The University of Sheffield
School of Architecture

Interactive urban form design of local climate scale in hot semi-arid zone

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Acknowledgement

For the sake of Allah,
To my heart; prophet Mohammad peace and blessings upon him

To my dear parents, wife and children,
To my parents in law and all of my brothers and sisters

Thanks go to all my teachers, to all my colleagues who have helped me in this research and to professor Stephen Sharples

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And to the soul of humanity

The reader is kindly asked to take into consideration and view with compassion the fact that the author is not writing in his first language especially with reference to the minor differences between the written UK and USA English.

Summary

From a sustainability point of view, urban form design has to consider climate that affects thermal performance of outdoor spaces and in turn pedestrian comfort, indoor energy consumption and climate change. It has been argued that the complexities of urban climatology prevented the connection between climate knowledge and urban planning practice and to wholly assess urban patterns by measurements. Urban climatology is a multi interdisciplinary fields related to form (fabric + pattern); vegetation, human biometeorology and comfort scaling, meteorology, architecture, urban planning, urban design, landscape, heat transfer physics, pollution, urban health, remote sensing ....etc are examples of involved fields. The primary aim of this research is to analyze and assess thermal impacts of urban developments in Cairo as a reflection of effective, ineffective built environment and to promote an implementation of appropriate sustainable urban form on a climate basis between the eastern western patterns mixture in a mega city like Cairo.

From these standing points, two existing neighbourhood cases were numerically examined using ENVI-met3.1 as a first time in a climate based urban planning research to assess the thermal performance of about 1 km^2 neighbourhood's outdoor spaces. ENVI-met3.1 combines almost all thermal interactions of built environment except those of anthropogenic (such as from transportation and HVAC systems) and green house gases' heating. An important preparation stage took place using GIS and sub-methodological solutions to get all needed input data for simulations. Modelling trees without measuring its foliage parameters and output data extraction are two sub-methodological techniques used in this research to help modelling and assessing the cases. Simulations held in summer time for two base cases and three alternatives for each case consumed about 15 months following a suggested design model to embed what is so called urban passive cooling system and tools within the design procedure of the urban form. The shaded-unshaded urban avenues, clustered form, GreenSect, are examples of the passive tools applied. Results of this research give implications for urban planners by strongly relating urban form thermal performance with its population density, housing strategy and land uses. Moreover, results give approaches for not only predicting present day urban land uses by the application of the URban PLAnning thermal comfort model, URPLA but also give approaches to adapting urban developments for climate change by using URPLA with a morphed meteorological data. This research work received a chance May 2010 for its resulted implications to be applied in an EPSRC project; URban River corridors and SUstainable Living Agendas, URSULA.

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Fahmy, M. and S. Sharples (2009a). "On the Development of an Urban Passive Thermal Comfort System in Cairo, Egypt." Building and Environment 44(9): 1907-1916.

Fahmy, M., A. Trabolsi and S. Sharples (2009). Dual Stage Simulations to Study Microclimate Thermal Effect on Comfort Levels in a Multi Family Residential Building. 11th International Building Performance Simulation Association Conference University of Strathclyde in Glasgow, 27-30 July.

Fahmy, M., S. Sharples and M. Yahiya (2010). "LAI based trees selection for mid latitude urban developments: A microclimatic study in Cairo, Egypt." Building and Environment **45**(2): 345-357.

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Introduction: Extremely hot suburban Cairo

a – Forward:

The total environment consists of the natural and built environments and the aim for environmental design is to achieve thermal, aural and visual physical comfort together with psychological comfort for indoor or outdoor conditions.

In the early years of the 20^{th} century the ideas around urban housing were concentrated on the need to accommodate populations within industrial communities (Allam and Geith 1995; Bernhardt 2005). Places for people to gather for social events were incorporated into the town planning theories. Eventually, the town areas grew and radiated to form more complicated patterns and this gave rise to a branch of studies in the late 1960s known as urban planning (Lynch 1960; Lynch and Hack 1984; Kreditor 1990; Schurch and 1999). Consequently, urban planning and its complex related topics have grown in both qualitative humanities subjects and quantitative science subjects. But these different disciplines haven't met in practice of urban climate (Eliasson 2000; Ali-Toudert 2005; Oke 2006). Therefore, this study is examining the relationship of the outdoor thermal performance and pedestrian comfort with form design principles, urban planning and usage of vegetation, fig (i).

It has been seen over the last 30 years of urban climate research that the application of passive techniques on a scale bigger than a single building can maximize the benefits in terms of energy saving, minimize climate change effects, improve pedestrian comfort and well being (Rosenfeld et al. 1995; Akbari et al. 2001).

This research investigated approaches to improving, by urban form design, the thermal performance of the urban patterns at the new urban developments in Cairo, Egypt. In this study, patterns at the neighbourhood local climate scale of about 1 km^2 have been investigated by numerical simulation, predominantly using the software package ENVI-met, which was the main analysis tool. This thesis will travel through urban planning theories, outdoors thermal comfort concepts, and try to investigate how climate, climate change, planning theories, and policies can affect the thermal performance of neighbourhoods. This research took place to find keys of relating climate knowledge to the applied urban planning in Cairo, Egypt in order to consider pedestrian comfort, reducing energy consumption and climate change effects.

b – Problem definition:

In a hot climate country like Egypt many planning projects have been produced and executed to cope with population growth (El Araby 2002; Ali 2003). In Cairo, the overwhelming rate population growth did not allow time for full environmental studies for both the built and the natural environment where buildings and open spaces have to be adequately climate responsive. Urban form is strongly dependant on climate interactions which can amplify or moderate impacts on human thermal comfort.

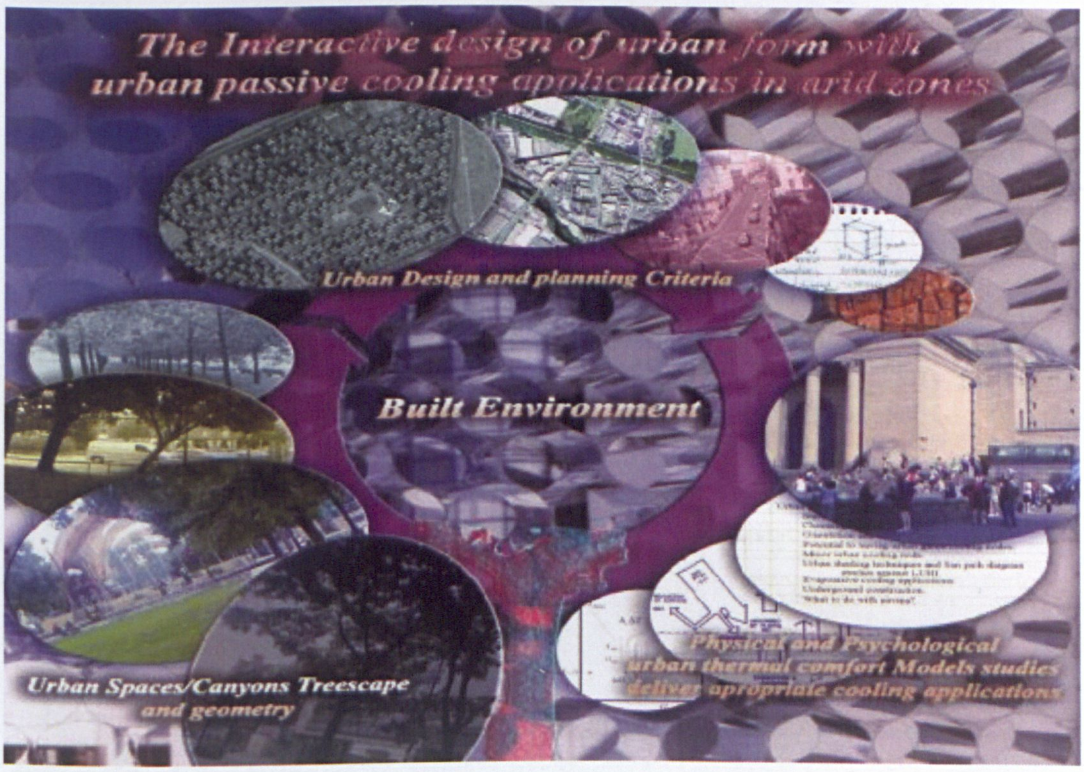

Figure i: Thermal environment tree, Photoshop edited graph for the author.

Cairo, N 30° 7', E 31° 23', is the capital of Egypt and located at the node at which the River Nile splits into two branches. It has been established in the 6th century BC, about 64 years in the Hijjry lunar Calendar. Cairo showed four time periods of urban planning developments based on political and economic shifts (Stewart 1999; Stewart et al. 2004; Yin et al. 2005). Two neighbourhood case studies in Cairo will be presented for a detailed analysis of passive urban design. The first case, the Fifth Community of the new Cairo, fig (ii), is a new suburban project that was quickly occupied due to the good level of public and private funding and the high reputation the development. The second case is in Misr Al-Gadida, fig (iii), which is another community in Cairo built about 80 years before the Fifth Community. The different urban forms and patterns in both cases affected their thermal performances due the different land uses, housing types, population density and others.

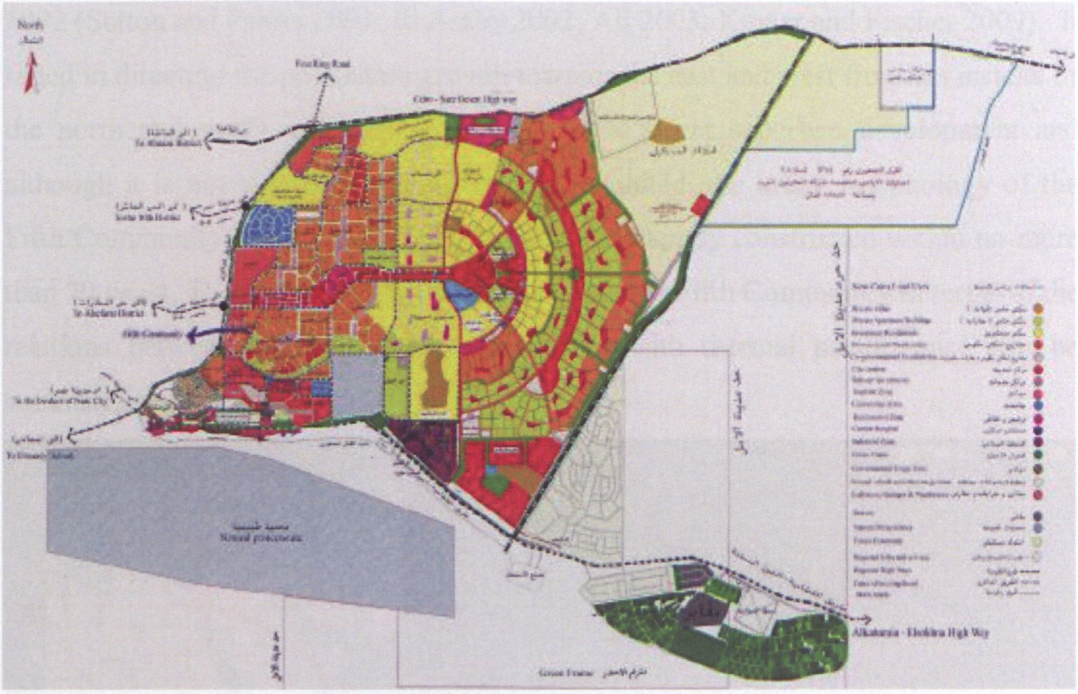

Figure ii: New Cairo Land Use (NUCA 2006).

Figure iii: Cases relation to Metropolitan Cairo, adapted from Google maps.

As the first case study is one of a growing number of new urban developments around Cairo, its ability to move towards sustainable development has attracted research attention. Urban planning faults reported led to many informal areas and to the failure of Greater Cairo's master plan which have been issued in 1970, 1982 and 1992 (Sutton and Fahmi 2001; El Araby 2002; Ali 2003; Kipper and Fischer 2009). It failed in directing the population growth towards the east and west frontiers instead of the north and south metropolitan areas. As a recent suburban development and although it is not yet 100% completed and inhabited, the urban morphology of the Fifth Community as part of New Cairo, has been rapidly constructed within no more than 20 years. The most obvious comments about the Fifth Community in terms of the relations between urban planning and design with thermal performance can be summarized as following:

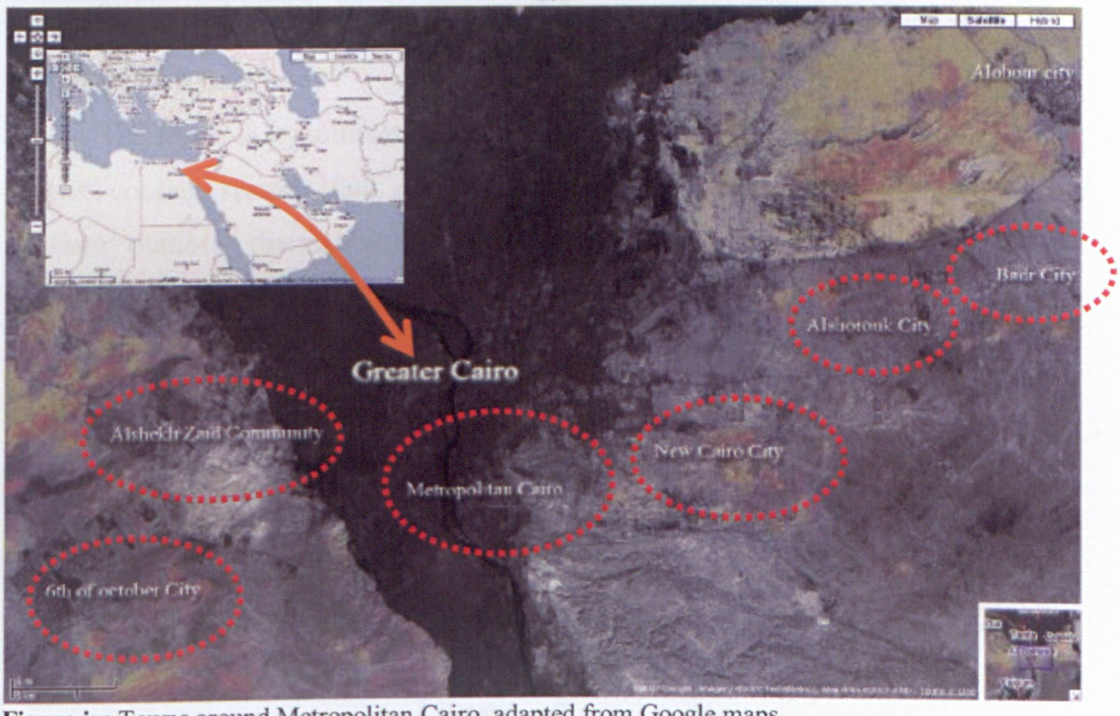

Figure iv: Towns around Metropolitan Cairo, adapted from Google maps.

1- From an urban planning point of view, it was planned in the late 1970s and early 1980s to attract the large population of metropolitan Cairo as part of a new satellite town's series, fig (iv). Present day planning and application methodology depended on "*those protocols used by planners, traffic engineers, environmentalists, urban designers, landscapers, architects, land-use attorneys, developers, bankers and marketing experts, which has built the precarious Babel of current practice*" (Duany 2002), p-255. Those communities became automobile anthropogenic heat sources dependent on metropolitan Cairo for all their infrastructure and utilities. Accessible pedestrian networks to community facilities, transport choice opportunities, energy conservation measures, green structure, built environment development, public spaces and parks are deficient.

2- From the thermal comfort design point of view, the western fabric type of suburban separated residential buildings increases local urban warming by allowing exposed surfaces to experience direct solar gain. There is no evidence for passive cooling technique or application being pre-planned for usage there. Moreover, the changed land uses, policies, and uncontrolled population growth has resulted in more problems such as an increased use of mechanical cooling, automobile dependent communities and hence more anthropogenic heat emissions. This is all in a time of climate change and higher oil and energy prices.

c - Research hypothesis:

The research hypothesis being tested in this study is whether or not embedding passive cooling systems into the design of urban patterns and forms can actually alleviate outdoor thermal stress and provide better thermal comfort levels for pedestrians in hot climates.

d - Research methodologies:

Conceptually, research methodologies follow the stages shown schematically in fig (v). This figure indicates the research iterating methodology between inputs, analysis, application and testing which combines to some degree how architects, urban planners and designers may think to start offering master plans alternatives.

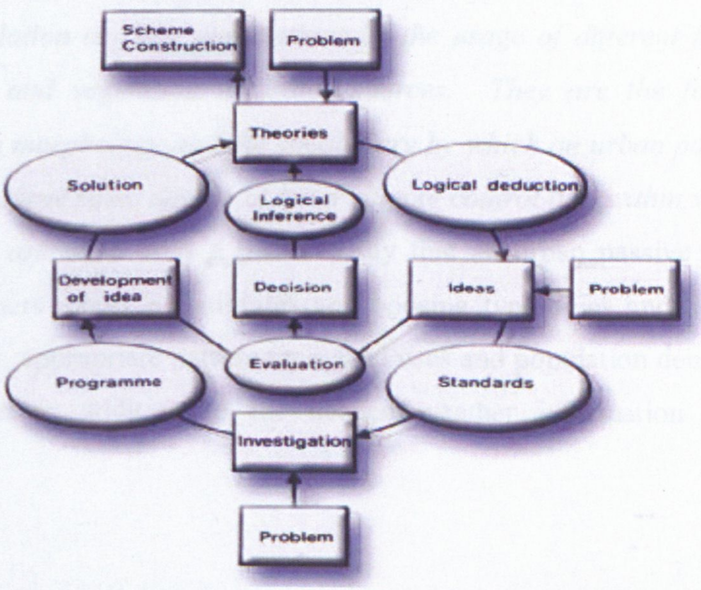

Figure v: Research and design process adapted from (Moughtin 2000).

Two case studies were chosen in the Egyptian capital, the Fifth Community and Misr Al-Gadida, to help illustrating through comparisons based on the urban thermal performance how differences in urban patterns land uses and population densities affect the outdoor climate conditions and in turn pedestrian comfort and indoor conditions.

e - Research Objectives:

The overall research objective, which is shown schematically in sketches by the author in figures (vi) and (vii), is to design a passive urban pattern. The detailed objectives are to:

1- Improve the classic urban planning using climate knowledge through research and design by investigating a suitable fabric unit and housing typology, spatial and vegetation structures based on specific land use and urban form compactness which in turn has been generated from specific population density. Climate knowledge will be introduced to the design process and product in terms of passive physical adjustments. These adjustments are considered the passive tools with which the fabric unit (housing type), spatial and vegetation structures will be geometrically adjusted upon climate conditions within the selected cases built environments. By this way urban passive tools can be to some extent the solution to the lacking connection between climate knowledge and its applied practice and offer architects and urban planners and designer an easy methods for draw their ideas climatically.

2- Define urban planning tools of passive thermal cooling to control the thermal performance of urban canyons at street level of the urban canopy layer, UCL. *Urban passive cooling tools are not the cooling techniques by shading, evaporation or ventilation or their applications by the usage of different fabric details, orientation, and vegetation or water sources. They are the format methods of the urban morphology and the vocabulary by which an urban passive form designer can achieve some degree of local climate control and within which passive applications are used.* It is a place to say that an urban passive form designer is who gathers inputs of buildings and housing typologies and design details as an architect, appropriate pattern type, land uses and population densities as an urban planner in addition to the needed weather information as a climatologist.

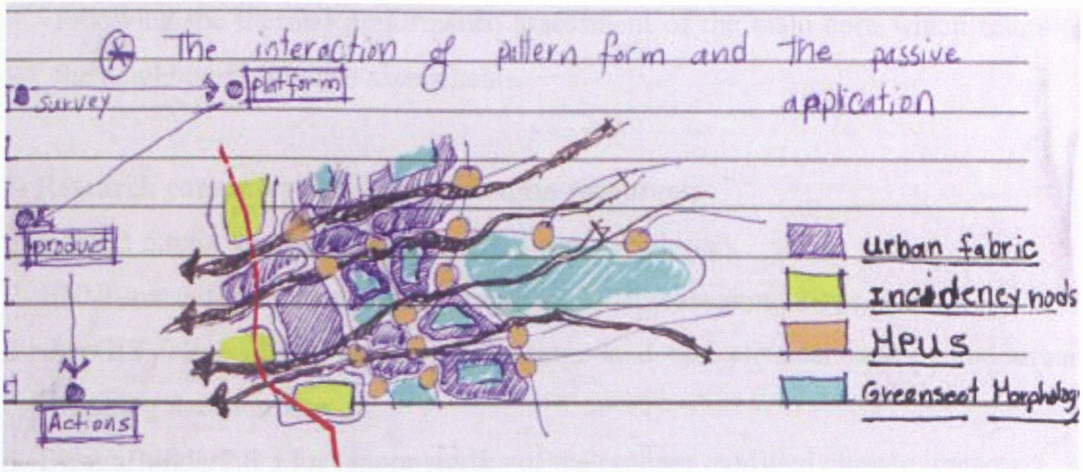

Figure vi: Freehand sketch of the author illustrating initial urban spatial design, i.e. usage of the urban passive tools into urban form to be capable of ventilation initiation due to pressure difference with orientation and aspect ratios, shadowing, evaporation and other passive cooling applications; the red axe line demonstrates that an urban form unit can be generated to produce pressure difference areas capturing amount of solar radiation, his has been published in (Fahmy and Sharples 2009a).

The red axe passes through the incidency nodes subjected to sun rays that make pressure difference in reference to the shaded areas. The orange color is multipurpose urban spaces, MPUS acting as a public social point, circulation distribution point, and a cooling node that is why it is called multipurpose urban spaces. The Cyan color is green areas distributed along with the sectional line of the urban planning unit from its centre and urban core to its urban rural reserve which is called Transect by the congress for new urbanism, CNU, and regarding they are green areas, hence Green + Transect can be called GreenSect (Fahmy and Sharples 2008a). The brown arrows are the stimulated wind directions.

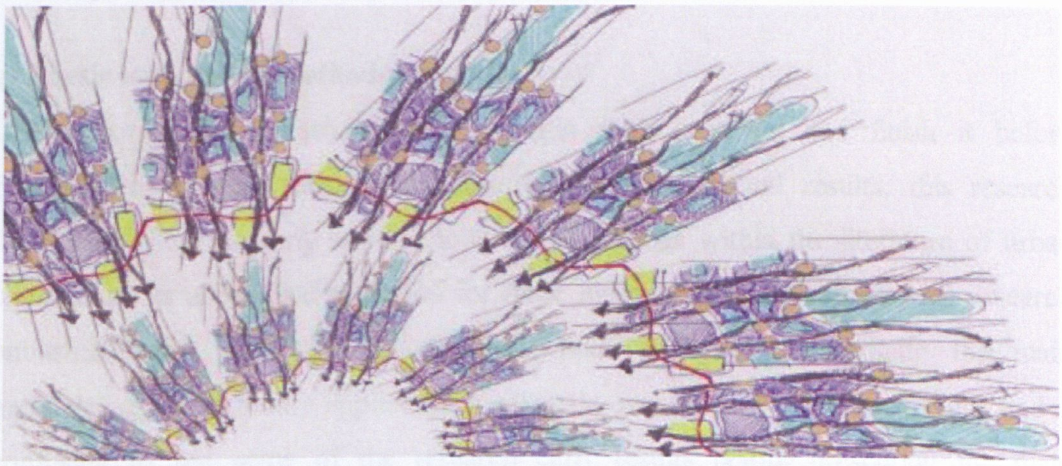

Figure vii: Urban array of passive form due to the iterating turbulences or cooling streams produced by pressure difference, a free hand schematic diagram of the author edited by Photoshop package.

3- Investigate the green structure based on human walking speed and the neighbourhood 5-15 minutes walking concept and the suitable urban trees for the cases selected provided that their examined thermal performance is proofed.

4- Provide an approach to quantify urban form design elements to adapt master plans for present and future times based on pedestrian thermal comfort. In this respect, research reports a comfort based urban planning land use parameters prediction following the thermal performance assessment of the main core which refers to the neighbourhood scale assessments.

f- Research computer Softwares and data resources:

1- Ecotect 5.6 for sun path, weather and thermal analysis.

2- ENVI-met 3.1 numerical CFD package for local scale simulations.

3- ArcGIS 9.2 package for aerial imaging, land use physical studies and urban planning decision support.

4- DesignBuilder2.0.5 for indoor studies of the outdoor modified climate impacts.

5- Photoshop 7.0 for graphics editing.

6- EnergyPlus4.0 for weather data files conversions.

7- ASHRAE climatic raw data files written in Egyptian Typical Meteorological Year format, ETMY based on 30 years of WMO Station no.623660 records from Cairo's international airport meteorology station, the nearest one to both of the neighbourhood case studies.

8- Microsoft office and Endnote for thesis editing.

g- Thesis structuring methodology:

Unlike normal theses structures that begin with literature and finish it before beginning to present research methodology, milestones and results, this research thesis has mixed its early sub-methodological findings within the literature of urban climatology as an applied examples for three reasons. First, as some of the research published work was sub-methodological pilot studies to investigate the main methodology itself before applied on local scale case studies, the reader might find it confusing to see some of the research early results before presenting the main methodology; there was a balanced weight for either to include them in literature and explain why it happened or to include in the main core after the main methodology while they should have preceded concluding the passive design methodology. But since the local climate scale cases, had a considerable number of pages in chapter five of the thesis, the decision was to include them in early chapters. Second, these studies took place within literature to illustrate chapter by chapter, fig (viii), an applied practice for studying urban climate cases due to lack in such studies for Cairo. *These early studies explains the need for urban form passive design methodology (Fahmy* *and Sharples 2008b) which is a result from chapter 1, impact of different urban forms' was presented in (Fahmy and Sharples 2008c) resulted in chapter 2, and some passive tools and spatial structuring for urban forms (Fahmy and Sharples 2009a) as resulted in chapter 3.* These pilot studies were then used to draw a whole picture about the applied urban passive form design as summarised at the end of chapter three. Eventually, all research published sub-methodological outputs included in thesis chapters from one to three have been applied to examine the bigger neighbourhood climate cases of the Fifth Community and Misr Al-Gadida in chapter five preceded by description and urban planning analysis for these bigger cases in chapter four. The last reason for this structure methodology is to help easing data flow portion by portion for the reader to cope with the climatology, urban planning, and urban design literatures as indicated in fig (i), rather than to mix all these different disciplines' literatures related to urban climate together for the sake of separating previous work from the main thesis work.

Literature review of the urban climate physics is presented in chapter one as an extensive review in order to draw a picture for urban form passive designer whose background might not be matching, followed by some passive tools investigation in chapter two which has been extended in chapter three with few more passive tools after analysing the urban planning literature as the other face of urban climate coin. In this respect, as the neighbourhood is considered to be the urban development unit, passive design tools embedded in the urban morphology of a neighbourhood can be considered the key relations might caused lack in connections between climate knowledge and a climate based urban practice.

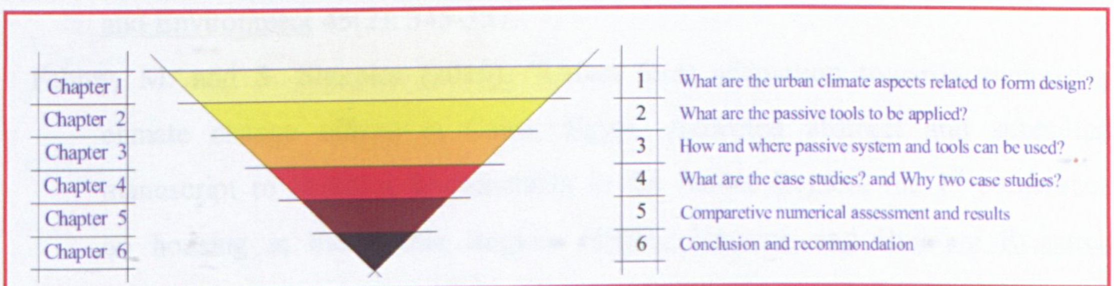

Figure viii: Thesis zooming illustration of the structure towards conclusions.

h- List of Research Published Work:

Fahmy, M. and S. Sharples (2008a). Extensive review for urban climatology: Definitions, aspects and scales. 7th International Conference on Civil and Architecture Engineering, ICCAE-7. Military Technical Collage, Cairo May 27-29.

Fahmy, M. and S. Sharples (2008b). "The need for an urban climatology applied design model, [Online]. Available at: http://www.urban-climate.org/IAUC028.pdf." The online newsletter of the International Association for Urban Climatology **2008**(28): 15-16.

Fahmy, M. and S. Sharples (2008c). Passive design for urban thermal comfort: a comparison between different urban forms in Cairo, Egypt. PLEA 2008 - 25th Conference on Passive and Low Energy Architecture. University Collage of Dublin, Dublin, 22nd to 24th October 2008. Dublin, UK, October 22-24.

Fahmy, M. and S. Sharples (2009a). "On the development of an urban passive thermal comfort system in Cairo, Egypt." Building and Environment **44**(9): 1907-1916.

Fahmy, M. and S. Sharples (2009b). Once upon a climate: arid urban utopia of passive cooling and the diversity of sustainable forms. SUE-MoT2009 Second International Conference on Whole Life Urban Sustainability and its Assessment. Loughborough University April 22-24.

Fahmy, M., A. Trabolsi and S. Sharples (2009). Dual Stage Simulations to Study Microclimate Thermal Effect on Comfort Levels in a Multi Family Residential Building. 11th International Building Performance Simulation Association Conference University of Strathclyde in Glasgow, 27-30 July.

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Chapter One: Urban thermal performance

1.1 Introduction

In order to assess thermal impacts of outdoor spaces concluded from specific urban forms, an understanding of outdoor climate conditions, thermal interactions and exchanges between different elements in addition to pedestrian comfort have to be established. Urban form interacts with its climate due to heat transfer and exchanges between canyons surfaces and its urban elements. Form performance is due to solar movements where short-wave radiation is absorbed or reflected. The absorbed heat is re-radiated as long wave radiation after a certain time, the amount depending upon wall and ground physical properties, fig (1-1/a). More complication takes place when a pedestrian moves or stands in the urban environment, as human biometeorology interacts with all the climate parameters, fig (1-1/b). In addition, vegetation has an important role in modifying the radiation environment as it receives direct radiation, absorbs and emits other amounts of long wave radiation and also traps another amount of long wave radiation from under its canopies, fig (1-1/c).

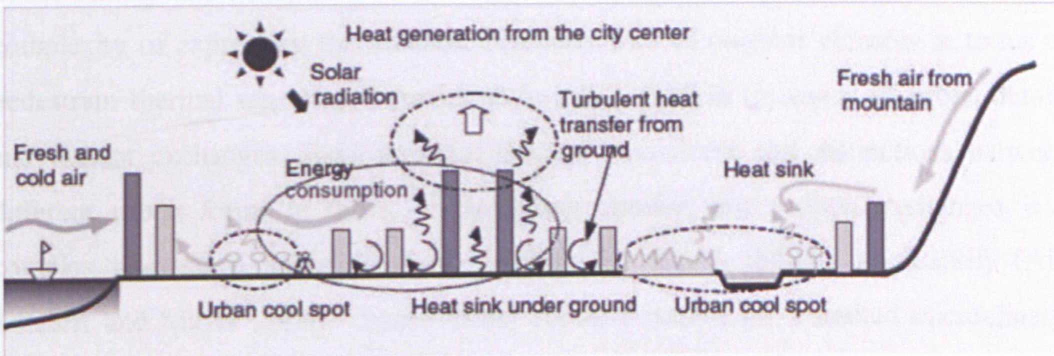


Figure (1-1/a): Urban heat circulations and conditions within outdoor environment differ from the indoor climatic conditions, adapted from (Murakami 2006).

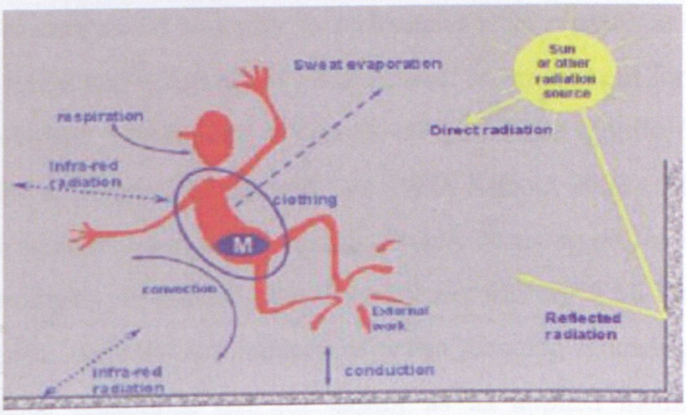


Figure (1-1/b): Basic heat exchanges between man and environment, adapted from (Havenith 2003).

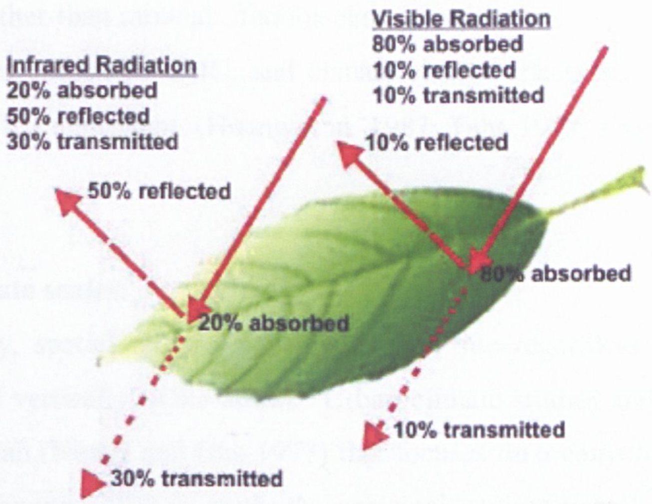


Figure (1-1/c): Vegetation role to modify radiation environment, adapted from (Shahidan et al. 2007).

Despite many investigations involved urban climate studies, there is still a lack of connection between these studies and applied design solutions for fabric and pattern forms specifically with regard to neighbourhood climate scale (Landsberg 1973; Oke 1984; Golany 1996; Eliasson 2000; Arnfield 2003; Ali-Toudert 2005; Oke 2006; Fahmy and Sharples 2008b). One reason for this missing connection is the complexity of expressing the transient characteristics of outdoor climates in terms of pedestrian thermal sensation, comfort scale and a method to assess all urban details and radiant exchanges. Environmental thermal assessment and distinctions between different urban forms in terms of pedestrian comfort and radiant exchanges is a complex interaction within the built environment that is difficult to quantify (Ali-Toudert and Mayer 2006). Some recent comfort studies for a limited microclimate areas have been presented to investigate the preferred pedestrian movement with respect to solar access and comfort sensation (Bruse 2005b; Bruse 2007). Two neighbourhood investigations aim only to understand wind regimes at street level with different aspect ratios and urban density but without an assessment for neighbourhood thermal and turbulent interactions reflected on pedestrian comfort and dedicated towards urban form design (Hussain and Lee 1980; Kubota 2008). This is the reason for saying ''*with respect to planning, studies directly focusing on the consequences of urban design strategies on comfort are dramatically lacking*''(Ali-Toudert 2005), p-51. In this respect, conventional method of urban planning is inadequate neither for controlling outdoor conditions nor for indoor as its applied methodology doesn't account for built environment adjustments at bigger scale than the micro and in specified way rather than rational. Indoor climate and in turn its energy consumption, greenhouse gases emissions, GHG, and climate change effects are not separate from outdoor climate but dependent, (Huang et al. 1987; Taha 1997; Rosenfeld et al. 2001; Akbari 2002).

1-2 Urban climate scales:

Generally, spatial dimensions of an urban site regardless its scale extends horizontally and vertically, (Oke 2006). Urban climate studies and scales definition started earlier than (Nunez and Oke 1977) that focuses on a canyon heat budget with the work of (Moneith 1973) to study the principal environmental physics and even earlier (Givoni 1963; Olgyay 1963). But with respect to precisely studying climate scales physics, the boundary layer climates of (Oke 1987) demonstrated an extensive research which has been extended by investigating urban climate instrumentations and measurements within different urban climate scales (Oke 2006). However, urban climate can be divided horizontally into;

1- Microclimate scale up to 1000m: it includes details of vegetation and buildings.
2- Local climate scale up to several kilometres which means including neighbourhoods.
3- Mesoscale climate: extends up to the tens of kilometres of a city.
4- Macro scale which concerns regional areas.

There are three main urban atmospheric vertical layers that hold the climate interactions within urban boundary layer, UBL, fig (1-2):

a- The urban canopy layer, UCL; from street level up to the mean height of roughness elements such as buildings and trees, referred to as z_h in fig (1-2). Effects of individual surfaces in this layer last until a blending occurs.
b- The roughness sub-layer, RSL, which represent the extended blending height of UCL effects from local scale surfaces. Its height z_r can be 1.5-4 z_h depending on the urban density (Grimmond and Oke 1999).
c- Inertial sub-layer, ISL; it can be generally described as the layer of the height at which a blending of RSL occurs at Mesoscale.

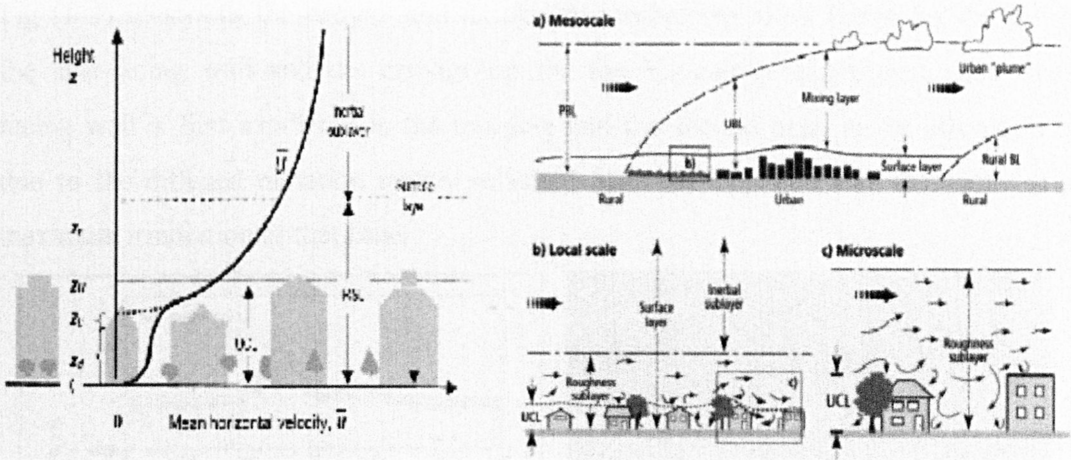


Figure (1-2/a, b): Urban wind profile and climatology layers, adapted from (Oke 2006).

1-3 Urban radiant interactions

As local scale climate is composed of a network of canyons, it can be studied in terms of only one canyon. Heat transfer regimes occur in outdoor spaces due to interactions between canyon surfaces, other surfaces and vegetation and then pedestrian interacts with all of these urban components. As solar altitude increases canyons receive more direct radiation in addition to diffuse and reflected radiations. A steady state heat transfer cycle begins by reflection and absorbance at canyon surfaces and including vegetation. The amount absorbed is eventually radiated as long wave radiation from walls, ground and also from vegetation (Oke 1987). After sunset all canyons start to release absorbed heat by convection and radiation.

Nunez and Oke (1977) investigated the basic knowledge on the energy balance of an urban canyon in their experiment in Vancouver (49° N). The study examined a street with an N-S orientation and an aspect ratio of H1/W = 0.86 and H2/W= 1.15. The net all-wave radiation of both walls and floor were explained as sensible heat fluxes Q_H, latent heat fluxes, Q_E and energy stored in materials ΔQ_S explained as follows:

$$Q^*_{Wall} = Q_H + \Delta Q_S \qquad \text{Eq. 1}$$

$$Q^*_{Floor} = Q_H + Q_E + \Delta Q_S \qquad \text{Eq. 2}$$

Assuming that anthropogenic heat is stored in materials, results of this study indicate that canyon geometry including its orientation has an influence on the radiation exchanges affecting the timing and magnitude of the energy mechanism of the canyon and its energy balance.

Fig (1-3) illustrates the canyon and its diurnal mechanism of all fluxes for the floor, the east-facing wall and the canyon-top for the Vancouver experiment. The east-facing wall is first irradiated in the morning and the second peak in the afternoon is due to the diffused radiation mainly reflected from the opposite wall that delivers a maximum irradiation at that time.

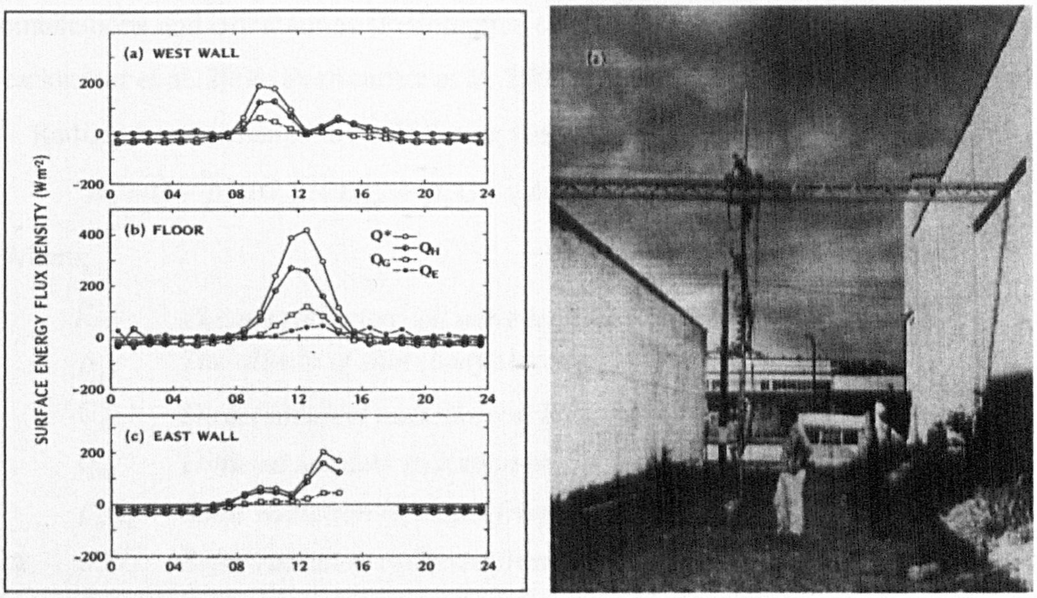


Figure (1-3/a, b): Vancouver Canyon experiment results held by (Nunez and Oke 1977) illustrating the structure that carried the sensors, and energy balances for each surface in 3 days.

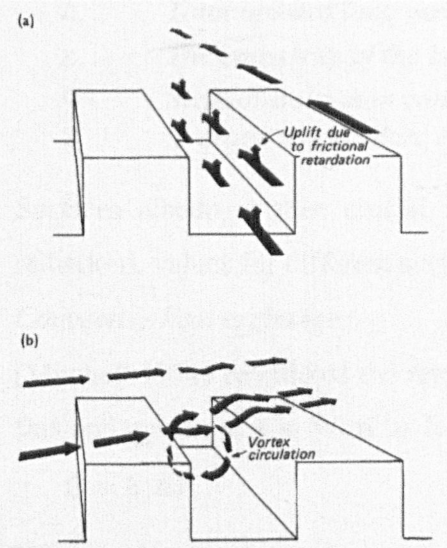


FIG. 5. Schematic airflow in the canyon with wind direction (a) parallel to and (b) at an angle to the longitudinal axis.

Figure (1-3/c): Vancouver Canyon suggested that an angled wind benefits canyon as part of pattern design, adopted from (Nunez and Oke 1977).

According to the N-S orientation, the floor is exposed at midday, the west and east walls about 1.5 hours before and after solar noon, where about 60% of the radiant energy surplus was dissipated as a sensible heat flux, 25-30% was stored in the materials and 10% transferred to air as latent heat. In the night-time the net radiant deficit is offset by the release of the energy stored within canyon materials and turbulent exchange which is minor. Suggested by (Nunez and Oke 1977), directing airflow at an angle in relation to canyon axis is important to pattern design, fig (1-3/c). They investigated the spatial distribution of air temperature within an urban canyon with a network of 63 measuring points set in a vertical cross-section of an urban canyon located in Kyoto, Japan, in a summer clear days. It was arranged with an increasing frequency towards the floor and walls to draw a thermal map for the Kyoto canyon.

Interactions of heat exchanges due to radiation and convection between humans and the surrounding environment have been investigated a variety of canyon combinations and orientations (Pearlmutter et al. 1999; Pearlmutter and Shaviv 2005; Pearlmutter et al. 2006; Pearlmutter et al. 2007):

1- Radiant heat exchange: by calculating the equation, fig (1-4);

$$R_n = (1-\rho_s)(G_{dir} + G_{dif} + \rho_h G_h + \rho_v G_v + L_d + L_h + L_v - \varepsilon\sigma T_s^4 \quad \text{Eq. 3}$$

Where;

R_n:	*The net radiation; all wave lengths* $(W.m^{-2})$.
ρ_s :	*The albedo of skin (body surface), in decimal factor.*
G_{dir} :	*Direct incident radiation on body* $(W.m^{-2})$.
G_{dif} :	*Diffused incident radiation on body* $(W.m^{-2})$.
$\rho_h G_h$:	*Solar radiation reflected from horizontal surfaces* $(W.m^{-2})$.
$\rho_v G_v$:	*Solar radiation reflected from vertical surfaces* $(W.m^{-2})$.
L_d :	*Total downward long wave radiation emitted by atmosphere* $(W.m^{-2})$.
L_h :	*Total upward long wave radiation emitted by ground* $(W.m^{-2})$.
L_v :	*Total upward long wave radiation emitted from verticals* $(W.m^{-2})$.
ε :	*The emissivity of the body, in decimal factor.*
σ :	*Stepfan-Boltz man constant* $(W.m^{-2}.K^{-4})$.
T_s :	*Average temperature of the body (K).*

Surfaces albedo is then crucial for estimating direct and diffused short-wave radiations, values for different surfaces are due to colour and texture (Taha 1997).

2- *Convective heat exchange*:

(Mitchell 1974) calculated the rate of convective heat transfer (*C*) or the sensible flux and measured it in W/m^2 as following;

$$C = h_c \Delta T \quad \text{Eq. 4}$$

Where:

C :	*The convective heat transfer or the sensible flux* $(W.m^{-2})$.
h_c :	*The transfer coefficient in W/m^2 °C, which is dependent on number of people in a group that affect the forced convection and on the air speed* $(W.m^{-2}.C^{-1})$.
ΔT :	*Difference between body temperature and the surrounding air temperature (°C).*

Human body heat exchanges with the environment are function of the air temperature the wind speed and the surrounding surfaces temperatures. In dry air the heat exchange depends on the human body temperature Tsk and air temperature Ta. Air is responsible for the convective exchange due to the difference in temperature between the body and the surrounding air, and the convective exchange is directly proportion with the square of air speed (Givoni 1998). Consequently, in humid conditions convection does not take place until the air speed reaches the limit at which the latent heat is released.

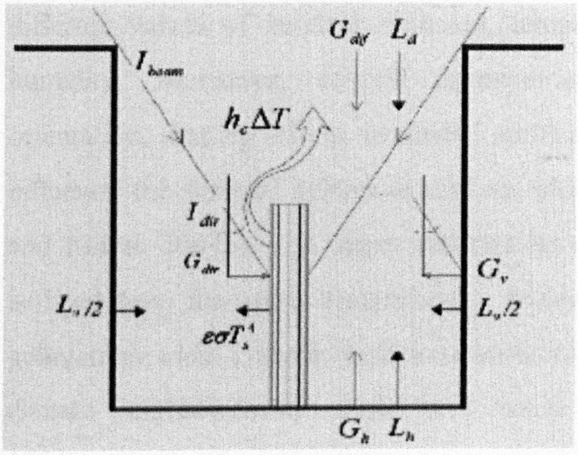


Figure (1-4): Human urban heat exchange, adapted from (Pearlmutter et al. 2006).

1-4 Canopy layer microclimate:

Interactions between canopy layer climate elements cannot be illustrated for each one separately, and their combined effect has a main role in human thermal sensation (Givoni 1998; Givoni et al. 2003; Bruse 2005a; Bruse 2007; Ali-Toudert and Mayer 2007a). The amount of solar radiation reaching the canopy layer is affected by location, sky cover and urban texture. Consequently the amount and temporal trends of heat regimes within canyons is different from one site to another even within the same location which affects surfaces and air temperatures. In arid climates there are three main cooling techniques; ventilation evaporation and solar sheltering which are shared to some extent between indoors and outdoors. But arid urban climates are dominated by nocturnal cooling of long wave radiation (Givoni 1998), especially where a clustered compact form is capable of releasing heat from structured multipurpose green areas (Fahmy and Sharples 2010). The same night cooling effect can be found in the Arabic courtyard houses (Waziry 2002).

In humid regions, generating air flow up to 4 m/s which a human can bear is a must when all of the body and clothes are soaked in sweat. Evaporation required for cooling is subject to the maximum evaporation capacity of air, which is a function of air humidity. However, the more vegetative or evaporation sources, the more cooling is possible in consideration of the ratio of required evaporation to the evaporation capacity. This ratio is commonly used to describe the Land Aridity, *0.2*–0.5 for semi-arid, 0.03–0.2 for arid, and below this for hyper arid regions (Bruins and Lithwick 1997; Bruins 2000).

Therefore, pattern heat budget calculations become very complex due to different values of incident radiation, temperature, wind speeds and direction and humidity. Moreover, canyon asymmetries, vertical properties, aspect ratio, orientation, shading effects, irradiated surface, vegetative structure and urban trees all influence the thermal behaviour and an added elements of complexity (Ali-Toudert and Mayer 2007b). As street canyons become narrower they become increasingly isolated from the upper atmosphere. Many studies have been held for symmetrical geometries while climatic variations attributable to the network and fabric of a local climate neighbourhood scale have rarely been investigated, (Mills and Arnfield 1993). A classification system for a city's urban form from a climatology point of view was presented by (Oke 2006) to help the application of climate knowledge in urban planning and development, fig (1-5). On the other hand, more compactness prevents adequate wind access, (Grimmond and Oke 1999; Georgakis and Santamouris 2006; Ghiaus et al. 2006; Oke 2006; Yoshida et al. 2006; Fahmy and Sharples 2008c).

Canyon's wind flow characteristics is derived from the wind flow of the inertial sub layer, ISL above the canopy layer (Oke 2006). This is affected by canyon orientation, slope and geometry. These characteristics can be represented in term of the building form ratios, H/W, H/L (Oke 1988), fig (1-5) and courtyard aspect ratio H/W/L (Ahmad 1994; Waziry 2004). Those characteristics can be demonstrated as follows:

1- Wind flows over an urban pattern near to the normal direction over the street axis show three types of flow systems depending on the buildings and pattern geometry and their specific combinations; fig (1-6).
2- These three air flow mechanisms can be described when H/W is large, medium or small magnitude; (a) the first case is called isolated roughness flow due to non-

interaction of air, (b) by increasing H/W interactions begin by slight separation of the canyon's air from the (ISL) wind and a single vortex appears, (c) double vortices produced due to increasing H/W and high separation from the (ISL), (Nakamura and Oke 1988; Santamouris et al. 1999).

3- The difference between surface and air temperatures in urban canyons together with a double vortex, is a consequence of parallel actions - stratification of the air temperature in the canyon and the increased wind speed upon the canyon at (ISL) as in Kyoto's canyon study by (Nakamura and Oke 1988), fig (1-7).

4- The speed of a single vortex due to a skimming wind regime of normal (H/W=1) canyon rooftop wind direction, (Hussain and Lee 1980) results from three definite sources: the air flow upon the canyon, the vertical layers of air inside the canyon, and the mechanism of advection from the buildings ends, (Ali-Toudert 2005).

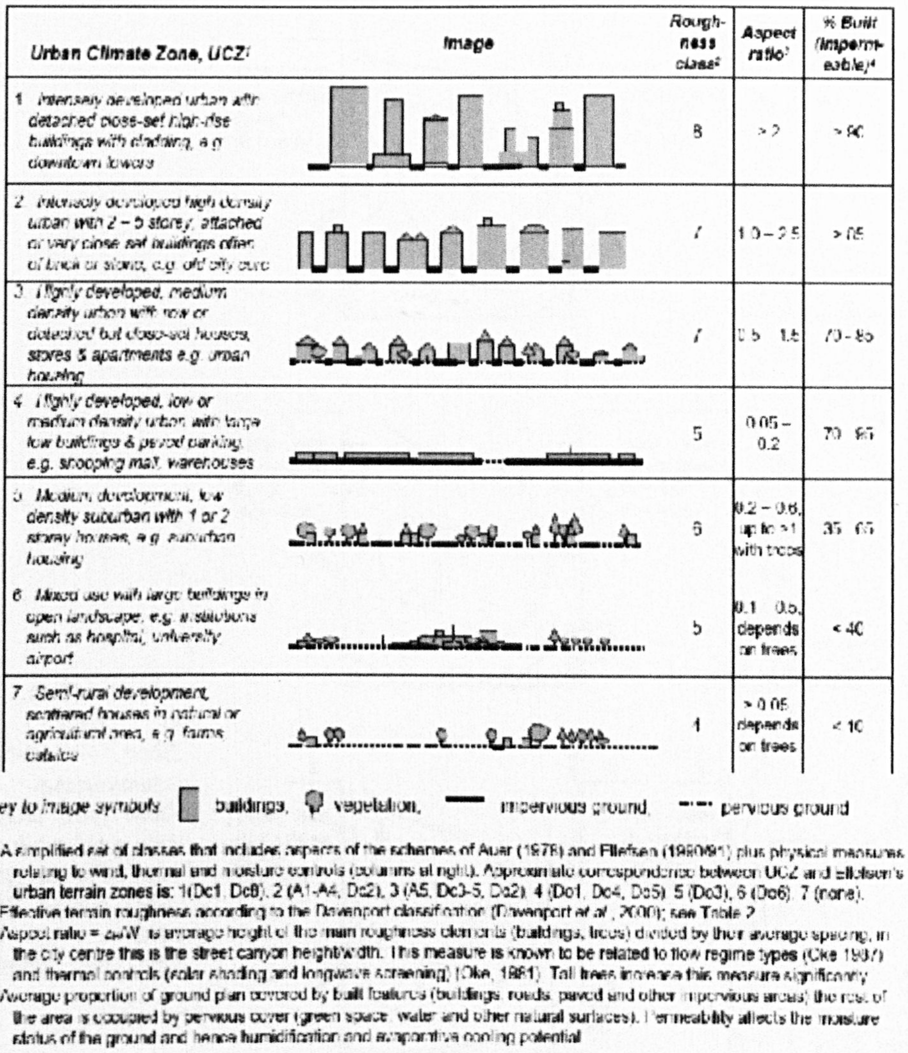
5- The relation between wind direction over the rooftop and in the canyon can be demonstrated as follows:

   a- For a normal rooftop wind direction the canyon wind direction is opposite and vice versa.

   b- For rooftop wind direction same to the canyon axe the canyon wind direction is same direction of rooftop due to a channelling effect.

   c- Most interesting is the intermediate case when flow above the rooftop has an angle-of-attack to the canyon axis. This produces a spiral vortex along the length of the canyon due to cork-screw type of wind action.

6- For the wind speed relations, the main one is the rooftop and the secondary is the canyon one, so for rooftop wind speed 1.5-2.0 m/s threshold the canyon wind starts to be generated not scattered while for 5m/s rooftop wind speed the relation between the two speeds become nearly linear for H/W=1.4, (DePaul and Shieh 1986).



Urban Climate Zone, UCZ[1]	Image	Roughness class[2]	Aspect ratio[3]	% Built (impermeable)[4]
1 Intensely developed urban with detached close-set high-rise buildings with cladding, e.g. downtown towers		8	> 2	> 90
2 Intensely developed high density urban with 2 – 5 storey, attached or very close-set buildings often of brick or stone, e.g. old city core		7	1.0 – 2.5	> 85
3 Highly developed, medium density urban with row or detached but close-set houses, stores & apartments e.g. urban housing		7	0.5 – 1.5	70 - 85
4 Highly developed, low or medium density urban with large low buildings & paved parking, e.g. shopping mall, warehouses		5	0.05 – 0.2	70 – 95
5 Medium development, low density suburban with 1 or 2 storey houses, e.g. suburban housing		6	0.2 – 0.6, up to > 1 with trees	35 – 65
6 Mixed use with large buildings in open landscape, e.g. institutions such as hospital, university, airport		5	0.1 – 0.5, depends on trees	< 40
7 Semi-rural development, scattered houses in natural or agricultural area, e.g. farms, estates		4	> 0.05, depends on trees	< 10

Key to image symbols: buildings, vegetation, impervious ground, pervious ground

[1] A simplified set of classes that includes aspects of the schemes of Auer (1978) and Ellefsen (1990/91) plus physical measures relating to wind, thermal and moisture controls (columns at right). Approximate correspondence between UCZ and Ellefsen's urban terrain zones is: 1(Dc1, Dc8), 2 (A1-A4, Dc2), 3 (A5, Dc3-5, Dc2), 4 (Do1, Do4, Do5), 5 (Do3), 6 (Do6), 7 (none).

[2] Effective terrain roughness according to the Davenport classification (Davenport et al., 2000); see Table 2.

[3] Aspect ratio = z_H/W is average height of the main roughness elements (buildings, trees) divided by their average spacing, in the city centre this is the street canyon height/width. This measure is known to be related to flow regime types (Oke 1987) and thermal controls (solar shading and longwave screening) (Oke, 1981). Tall trees increase this measure significantly.

[4] Average proportion of ground plan covered by built features (buildings, roads, paved and other impervious areas) the rest of the area is occupied by pervious cover (green space, water and other natural surfaces). Permeability affects the moisture status of the ground and hence humidification and evaporative cooling potential.

Figure 1-5: Urban climate zones arranged in deceasing order of their ability to impact local climate, (Oke 2006), based on (Ellefsen 1990/1991).

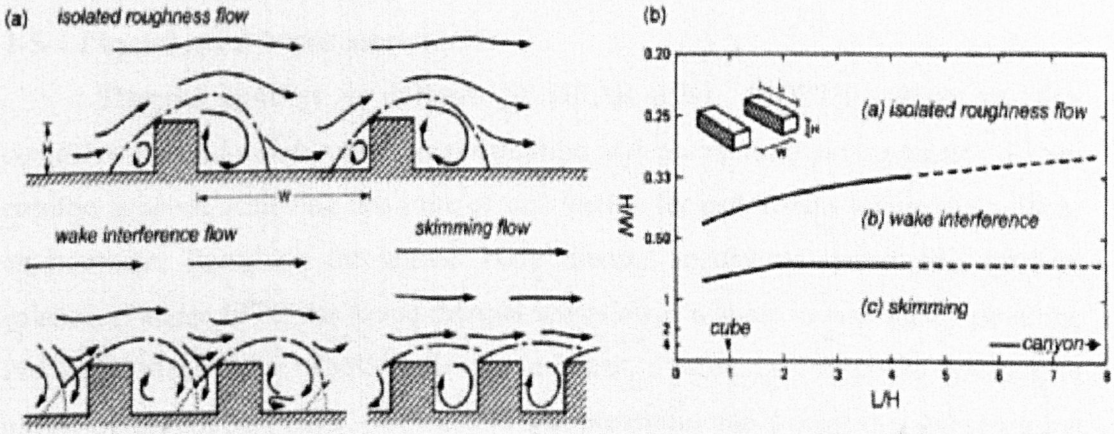


Figure 1-6: (a) Wind flow regimes and (b) corresponding threshold lines dividing air flow into three regimes as function of canyon (H/W), adapted from (Oke 1988).

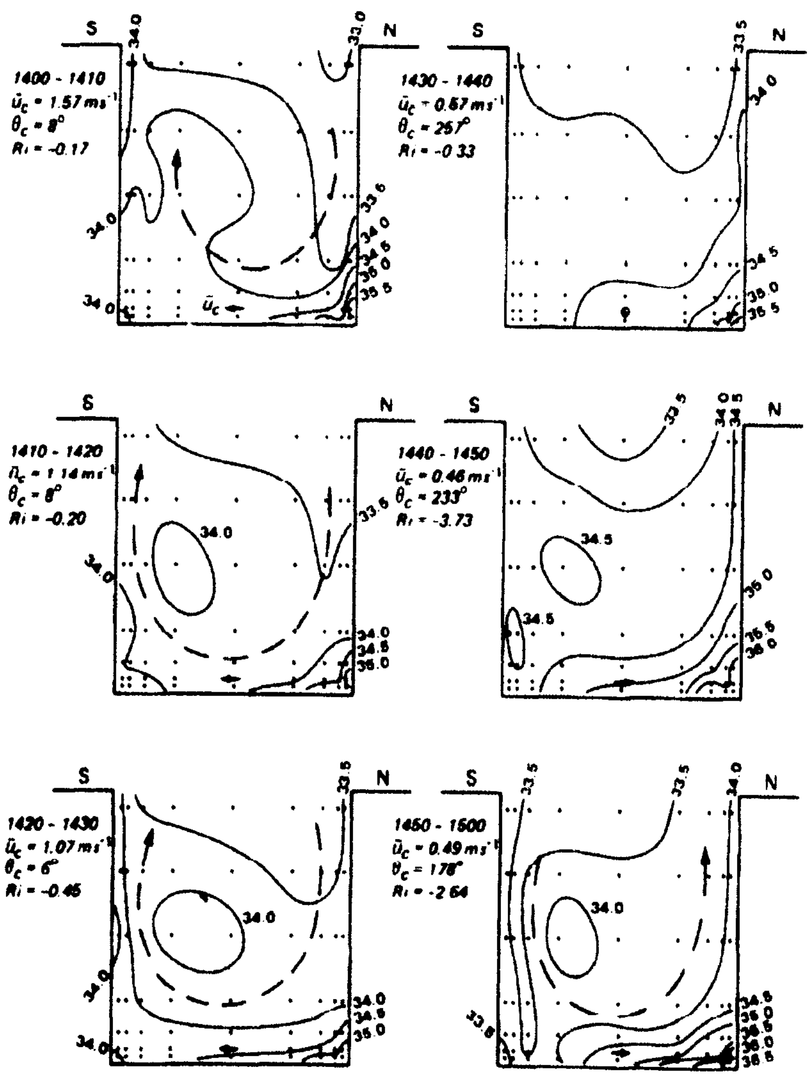


Figure (1-7): Kyoto canyon map of temperature – wind, where measurements were taken from 1400-1500 in the midday with time intervals of 10 min. in 29-30 August 1984, adapted from (Nakamura and Oke 1988).

1-5 Urban thermal comfort:

1-5-1 Physiological based assessment:

Thermal comfort is defined (ASHRAE 1981; ISO7730 1984) as "*that condition of mind which expresses satisfaction with the thermal environment*". Urban comfort is about achieving this state of *satisfaction* for pedestrians within the outdoor environment. Based on the human body thermal regulatory system and its heat balance, (Fanger 1972) has found thermal sensation as a guide in making a 7 point the Predicted Mean Vote PMV scale for comfort. Preceding Fanger to investigate physiological comfort basis, (Givoni 1963) in presenting the 5-point thermal sensation ITS scale considered the heat exchanges, metabolism and clothes. ITS has been extended to be the 7-point thermal index TS considering the rates of sweating determined by the balance between metabolic heat production and the heat lost by radiation and convection (Givoni et al. 2003). However, field measurements and questionnaires revealed that actual mean votes did not match PMV predictions for comfort as there are other non-physiological factors that should be involved (Oseland 1994; Oseland 1995; de-Dear and Brager 1998; Nicol and Humphreys 2002).

Fixed assumptions used to define comfort zones in ISO 7730 by applying the PMV and PPD experiments were held in a closed chamber with a group of people in the same ethnicity and in a static environment. It assumed a fixed skin area of 1.8 m^2 for a 70kg male and 1.6m^2 for a 60kg female with activity of 1 met = 58 W/m^2 and clothing of 1 Clo = 0.155 m^2K/W. These assumptions did not consider the properties of clothing that people wear, ethnicities body dimensions, cultures, capability of bearing native harsh climate etc (Havenith 2003). The general physiological concept is;

$$H=M-W \qquad \text{Eq. 5}$$

And $$M+W+C+R+P=0 \qquad \text{Eq. 6}$$

Where: *H is the total metabolic heat production* $(W.m^{-2})$.

W is the performed mechanical work by the body $(W.m^{-2})$.

M is the rate of metabolic action at which body utilizes oxygen and food to produce energy is measured in $W.m^{-2}$ *and 1 Met is 58.15* $W.m^{-2}$ *which is the metabolic rate of a seated person at rest.*

C is the convective heat exchange $(W.m^{-2})$.

R is the radiant heat exchange $(W.m^{-2})$.

P is the heat transferred due to perspiration $(W.m^{-2})$.

The Universal Thermal Comfort Index project led by the German meteorological service sponsored by European Cooperation in Science and Technology, COST, International Society of Biometeorology, ISB and World Meteorological Organization, WMO is trying to consider many inputs to validate the index and to make it reliable. Their primary comfort model is physiological but considers transient conditions even outdoors:

$$M + W + Q^*(Tmrt,v) + Q_H(Ta,v) + Q_L(e,v) + Q_{SW}(e,v) + Q_{Re}(Ta,e) + S = 0 \qquad \text{Eq. 7}$$

Where: *M is the metabolic rate (activity)* $(W.m^{-2})$.

W is the mechanical power (kind of activity) $(W.m^{-2})$.

Q is the radiation budget* $(W.m^{-2})$.

Q_H is the turbulent flux of sensible heat ($W.m^{-2}$).

Q_L is the turbulent flux of latent heat water vapour diffusion, ($W.m^{-2}$).

Q_{SW} is the turbulent flux of latent heat sweat evaporation, ($W.m^{-2}$).

Q_{Re} is the respiratory heat flux sensible and latent, ($W.m^{-2}$).

S is the stored heat ($W.m^{-2}$).

This model equation's meteorological inputs are the air temperature T_a, water vapour pressure e, wind velocity v, mean radiant temperature T_{mrt} including all-wave radiation exchanges considering walking speed of human as 1.1 m/s with an adaptive clothing insulation values between 0.4 and 2.6 Clo and subsets of environmental parameters that included 3 different levels of ambient temperature (mean radiant temperature was set equal to air temperature), 5 different air velocities, and 50% RH in a multi node simulations to predict the human comfort state based on the modified PMV model (Jendritzky et al. 1979; Fiala et al. 2001; Jendritzky et al. 2003; Fiala et al. 2005; Jendritzky et al. 2005). The modified PMV stands for the outdoor transient conditions and for the short-wave radiation whereas the basic PMV is for indoors and doesn't account for transient conditions.

1-5-2 Psychological adaptation:

Basically, meteorological or heat stress limits based only on physiological approaches do not succeed to match actual sensation and comfort levels not only indoors as described in the previous section but also outdoors (Nikolopoulou 2001; Nikolopoulou and Steemers 2003; Nikolopoulou and Lykoudis 2006). Users of urban spaces are more tolerant of a wider range of temperature variations, with plenty of clothing insulation so that in cold conditions they can use coats, scarves and gloves and vice versa. Psychological adaptation is about human natural subconscious perceptions and responses beyond the physics of the body. Behaviours are repeated diurnally and annually using the biological sensation to minimize the effects of changing conditions. Comfort models that have been used to calculate comfort levels physiologically have not been supported by field measurements. The '*adaptive model reflects a give and take relationship between the environment and the user*' (Brager and Dear 1998; de-Dear and Brager 1998; Humphreys and Nicol 2002; Nicol and Humphreys 2002; Humphreys et al. 2007). The understanding that urban details support climate sensitive planning and design has been widely acknowledged and realization of what the physical environmental adjustments can do for people to psychologically influence their comfort perception is being developed (Eliasson 2000; Eliasson and Upmanis 2000; Eliasson et al. 2007). Urban thermal comfort can be gotten closer to acceptable levels by fabric design (Ali-Toudert et al. 2005; Ali-Toudert and Mayer 2006). Few studies have tried to define how humans can adapt to comfort; there are three main ways to give such opportunities (Brager and Dear 1998; de-Dear and Brager 1998; Givoni 1998; Fiala et al. 2001; Huizenga et al. 2001; Nikolopoulou 2001; Humphreys and Nicol 2002; Nicol and Humphreys 2002; Nikolopoulou and Steemers 2003; Humphreys et al. 2007):

1- *Behavioural adjustments* or *physical adaptation*, which concerns what, is made by someone's personality such as personal adjustments for clothing, activity, posture, eating or drinking hot or cold, environmental adaptation in terms of design considerations and modification for urban spaces' details. It also refers to cultural and social adjustments that include organizational activities, siestas and dressings of each gender.
2- *Physiological acclimatization* or *adaptation* is a human response to the repeated circumstances in a specific climate region.
3- *Psychological adaptation* implies human natural and subconscious responses which illustrates what people can do in urban spaces, (Nikolopoulou and Steemers 2003):
    a- *Naturalness;* where people can tolerate climate regarding the transience and mobility of the outdoor conditions whereas metabolism and clothing have a significant effect.
    b- *Expectations*; where people can predict climate conditions and take the precautions needed.
    c- *Experience;* expresses the people short term and long term knowledge about climate that can be explained in a term of diurnal and annual saved data about the climate.
    d- *Time of exposure;* herein the most reason of thermal discomfort in hot climates. It is the spent time under the direct sun rays what increases the hot perception.

e- *Perceived control;* is stating that people in urban spaces manage their time and reason of being in that place, sitting place in order to increase their ability of tolerating a wide range of climatic conditions.

f- *Environmental Stimulation;* it is the effect of aesthetical environment values and personal perceptions that can be improved by solar shelters, orientation or urban trees.

1-6 Review of thermal comfort indices:

One of the points that a built environment has to be assessed upon is the pedestrian thermal comfort (Ali-Toudert and Mayer 2007a), therefore an understanding of how a thermal comfort index is driven and which one is the suitable one to use is important. Thermal comfort indices are built around thermal sensation experiments for assessing the indoor or outdoor thermal environments of places for human comfort as it is a needed to know how far indoor or outdoor conditions are from comfort. Some of those indices are intended to be used indoors and others to be used outdoors (Givoni 1998). Some are best for moderate regions and others are not (Ali-Toudert 2005). There are more than 100 thermal comfort indices (Jendritzky et al. 2002). Some of them are just indices of relationships between meteorology parameters such as air temperature plus wind speed in cold climates or air temperature plus humidity in hot climates. An example is the bioclimatic chart of Olgyay that indicates differences for the limits of a comfort zone if applied outdoors and cannot be used correctly for all climatic regions. Budget indices are based on heat in-out calculations or models for the human body considering heat perception to be indexed. Those later can be divided into two parts; first are the so called steady state heat budget models that have been introduced for indoor purposes (Hoppe 2002) but which are not necessarily compatible with field measurements. These indices include the Fanger PMV, effective temperature ET and standard effective temperature SET (Brager and Dear 1998; Humphreys and Nicol 2002; Spagnolo and de Dear 2003). A second type are models for indoor or outdoor conditions evaluation that consider part of or all net wave fluxes within fabric starting from (Nunez and Oke 1977), human heat exchange (Moneith 1973; Bruse and Fleer 1998; Pearlmutter et al. 1999; Bruse 2008), vegetation heat exchange (Kurn et al. 1994; Sailor et al. 2008a; Sailor 2008b) and urban anthropogenic heat gain (Taha 1997). Of this second type, outdoor standard effective temperature, OUT_SET* (Pickup and Dear 2000) is a development of the modified standard effective temperature SET*. Physiological effective temperature, PET (Mayer and Hoppe 1987; Hoppe 1999) introduces air speed of 0.1 m/s in a two node human body energy balance. (Jendritzky et al. 1979) developed the perceived temperature PT using Fanger PMV following the KLIMA-MICHAEL-MODEL which is based on the biometeorology of standard human body called Michael. This model has been adapted for considering transient conditions of urban areas and then improved by (Jendritzky and Nübler 1981) to account for all wave radiation types in terms of radiant temperature. Eventually, other models used to index human comfort depend on the so far called concentric layers (core to skin) dynamic human thermo regulatory as well as differentiating between model input for air temperature, humidity or wind speed (Stolwijk and Hardy 1966; Gagge et al. 1967; Gagge et al. 1986; Hoppe 1999; Pickup and Dear 2000; Huizenga et al. 2001; Bruse 2005b).

An environmental meteorological model, ENVI-met has been presented by (Bruse and Fleer 1998; Bruse 2008), with pedestrian traffic to model human comfort interactions within almost a complete budget of the built environment. It is capable of calculating human comfort depending the modified Predicted Mean Vote, PMV index of (Jendritzky and Nübler 1981) that account for outdoor transient conditions and all-net wave radiation. This is despite reported disadvantages of the PMV (Humphreys and Nicol 2002), and the numerical overestimations reported by (Spangenberg 2005) such as not calculating roof soil heat storage and global radiation overestimations by day and under estimations by night (Ali-Toudert, 2005).

The individual thermal comfort model, ITCM, (Bruse 2005b) is based on a dynamic two node model combined with agents moving along a grid area. The dynamic Effective Temperature, d(ET), generated from the ITCM in corporation with ENV-met model simulations "*is a thermal comfort indicator analogous to the "normal" Effective Temperature (Gagge et al. 1986) or PET (Hoppe 1999) but uses the actual dynamic skin and core temperature of the agent instead of the skin and core temperature under steady-state conditions*", (Bruse 2005a), p-138.

1-7 Urban comfort and climate change

1-7-1 Urban form adaptation

It is believed that global warming and climate change is caused by urban population increases, human welfare and the worldwide industrial growth (IPCC 2010). The direct impact is the increasing man made green house gas, GHG, emissions, of which carbon dioxide is playing a big role. A series of studies indicated that the climate is getting warmer with increasing urban heat island effects (UHI) (Oke 1976; Oke 1987; Roth et al. 1989a). Effects of urban climate change can be minimized by passive applications at the local scale (Taha 1997; Akbari 2002). Climate change impacts, from higher temperature and health issues to floods and energy consumption increases, can lead to completely different master plans for urban developments in order to adapt cities in the next few decades (Brundtland 1989; Akbari 2002; Gerald 2007; McEvoy 2007; Wilby 2007; Levermore 2008a; Levermore 2008b; David 2009; Knudstrup et al. 2009; Lu et al. 2009). Eventually, reducing GHG specifically in the residential and industrial sectors through an efficient adaptation will be essential and based upon governmental policies (Reilly et al. 1999; Santilli et al. 2005). As climate change is one of the key challenges of urban thermal performance, future energy consumption; scenarios to face climate change include the following (McEvoy 2007):

1- Increasing power resources to cope with future needs which are considered very hard and expensive regarding the globe conflicts and natural resources expiry.
2- Facing a great decrease in the national output due to the reduction or loss of power supplies needed to maintain social, economical, industrial progress and prosperity.
3- A smart growth scenario in combination with tackling the renewable sources seriously, urban and buildings passive designs opportunities by urban thermal design to encourage people to adapt their local and national thermal comfort indices and decreasing mechanical needs.

Therefore, residential sector adaptation for reducing carbon emissions could be more effective at the urban form local scale adaptation instead of single building scale policies. Urban form adaptation is a higher scale of climate based responsive urban planning through adjustments of the fabric, vegetation along with cooling surfaces; i.e. usage of urban passive cooling techniques (Huang et al. 1987; Akbari et al. 2001; Akbari 2002; Gill 2007; Fahmy and Sharples 2008a; Fahmy and Sharples 2009a). Specific dimensions between green cool islands using human being walking speed and his/her maximum walkable distance has been argued by (Fahmy and Sharples 2008a). The degree of compactness of a community can play an important role in estimating urban patterns, thermal performance and human thermal comfort prior to construction(Fahmy and Sharples 2009a). Moreover, it can be used as an adaptor to climate change as more compactness reveals more comfort regardless of the limitations for wind access.

1-7-2 Thermal effects of intensive form:

On the other hand, more compactness can increase UHI intensity (Oke 1976). It is a phenomenon characterizing urban centres whose air temperatures is higher than those in its rural neighbour. It is generated due to the heat stored in the built environment which increases air temperature at a place then another. In other words it is the difference between temperatures measured in the urban space and those in the non-urban space surrounding it. UHI has received growing research interest and there have been many studies in different climatic regions due the increasing number of people living in urbanized areas (Roth et al. 1989a; Hassan et al. 1990; Arnfield 2003; Offerle et al. 2005; Sofer and Potchter 2006; Matthias 2007; Roth 2007; Sailor and Dietch 2007; Santamouris et al. 2007). The aspect ratio of the urban canyon and UHI intensity increases with the increase of H/W, fig (1-8). The construction density, intensity of activities and traffic, urban canopy morphology, poverty and population are drivers for increasing city intensive form and in turn are reasons for the heat island effect (Landsberg and Maisel 1972; Balling and Brazel 1987; Grimmond and Oke 1999; Grimmond and Oke 2002; Harlan et al. 2006; Harlan et al. 2008).

The role of relative humidity in generating and maximizing heat islands effect as an interactive relationship between all of the local urban climatic conditions has been discussed by (Grimmond and Oke 1999; Holmer and Eliasson 1999). URHI, the urban relative humidity intensity, demonstrates the difference between the measured humidity in urban core and at rural urban areas (Robaa 2003). Surface roughness, moisture resources, and urban canopy heat exchange are the factors affecting urban humidity intensity.

A theoretical quarter neighbourhood in Cairo has been numerically simulated by (Fahmy and Sharples 2009a) and presented another type of meteorological heat island; the local urban radiant heat island, LUHI. By the same concept, it is the difference between the radiant temperature records or measures at the urban centre and outside of the urban centre.

The growth of urbanization is accompanied by higher levels of energy consumption for utilities and transportation. Urban energy consumption generates heat islands that modify local and microclimate around them. "*The heat island phenomenon is created as cities radiate less heat back into the atmosphere than rural areas, making cities warmer than rural areas*", (PRB 2007), p-12.

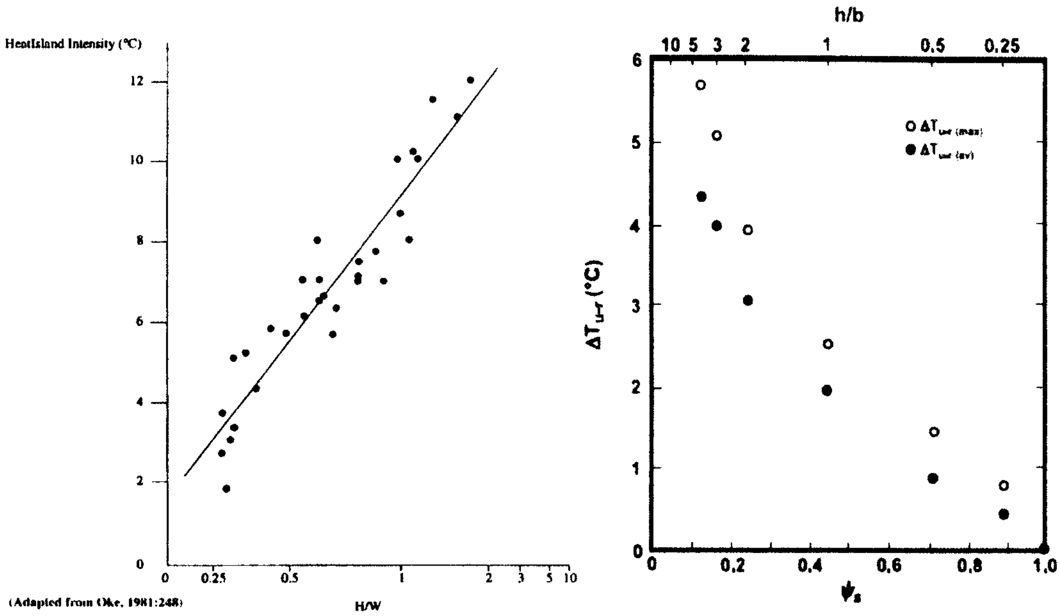


Figure (1-8): (a) Left; Urban heat island intensity and H/W, (b)right; triple relation between aspect ratio h/b, SVF and ΔT_{U-R} presented by (Kanda 2006), both graphs adapted from (Oke 1981).

Several studies have illustrated the strategies for mitigating UHI effects (Taha 1997; Akbari et al. 2001; Rosenfeld et al. 2001; Akbari 2002; EPA 2005; Roth 2007; Sailor and Dietch 2007) as follows:

1- Albedo modification.
2- Vegetation modification; increasing area, urban trees type selection...etc,
3- Combined albedo and vegetation modification.
4- Decreasing population densities or increasing networks areas at street levels but should be studied from the albedo point of view.
5- Increasing urban wind speed at street level.
6- Deformations for finishing materials geometry and physical properties.

1-8 Summary

Opportunities exist in urban design planning, decisions, and application to moderate outdoor urban spaces as a response to climatic conditions in order to try and achieve thermal comfort. An iterative method could be developed between the urban form and design tools and an assessment method to enhance urban spaces. Moreover, such an approach could raise the awareness for the necessity of a new urban planning renaissance based on the passive thermal design of urban patterns.

However, the assessment of outdoor comfort within the built environment is crucial to know how well the design is succeeding. An assessment that is based on only one meteorological parameter is not sufficient. From these stand points the conclusions of this chapter can be illustrated as:

1- Due to the complexity of built environment thermal interactions and the many interacted interdisciplinary fields, climate knowledge is still not related to urban planning in practice which means that an applied design model is needed, in this respect, fig (1-9) demonstrates a preliminary urban passive planning and design model as reported by (Fahmy and Sharples 2008b).

2- Despite the needed dual assessment of human thermal comfort level as well as thermal performance of the fabric itself which is expressed in physiological way, the psychological adaptation for comfort is the completion and can be expressed in design details for urban spaces.

3- These opportunities can be expressed as a passive design tools which could be technically well established in the field for smaller scales (Rahamimoff 1984; Shashua-Bar and Hoffman 2000; Bruse 2005a), but for a neighbourhood local climate scale it still a challenge to be assessed.

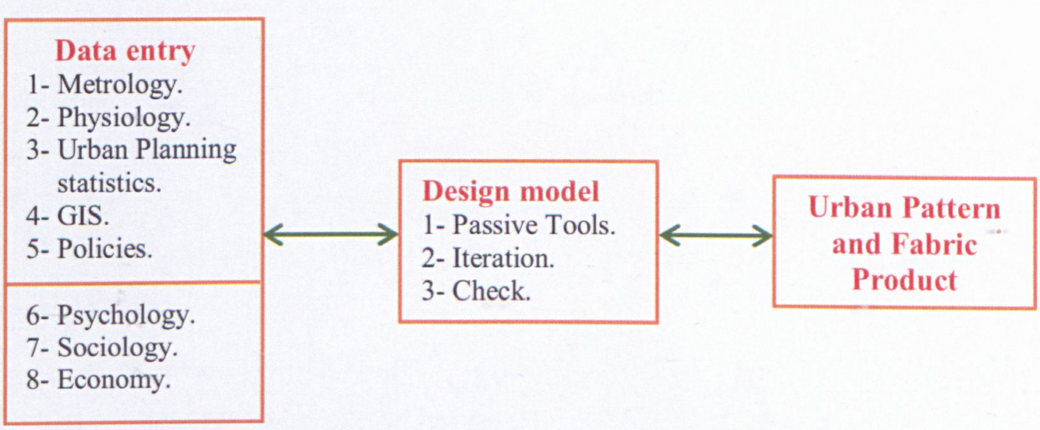


Figure (1- 9): The research preliminary urban passive planning and design model, titles 6, 7 and 8 in the data entry are not directly related to this research work.

Chapter Two: Urban planning passive cooling tools

2.1 Introduction

Urban passive cooling is the theory, methodology and practice of reducing the heat stresses by means of interaction and integration with the built environment. Population growth, the global acceleration of urbanization, climate change, transportation and higher rates energy consumption all contribute to urban thermal discomfort. In addition, due to the complexity of cities and urban developments, a combination of urban passive design tools should be applied rather than rationally designing compact cities or courtyard houses as vernacular architecture would suggest for hot climates.

Urban passive cooling tools are not the cooling techniques of shading, evaporation or ventilation or their applications by the usage of different fabric details, orientation, and vegetation or water surfaces. They are the methods of using buildings and housing typologies, appropriate pattern type, land uses and population densities, green structure and trees arrangements so that an urban passive form designer can use them to achieve some degree of local climate control and within which passive applications are used to achieve a so called urban passive cooling system. Therefore, urban passive form designer is who gathers inputs of buildings and housing typologies and design details as an architect, appropriate pattern type, land uses and population densities as an urban planner in addition to the needed weather information as a climatologist in an applied design model as concluded in chapter one.

In this chapter, a preliminary approach for the passive design methodology, as reported in the summary of chapter one, is presented in terms of passive design tools whereas data entry of that applied model for a local scale is taking place in the assessment of the neighbourhood cases in chapter five as mentioned in section (h) of thesis introduction. It is a place to mention that following the argument of the need for an applied passive design model by (Fahmy and Sharples 2008b), this chapter presents another two studies to continue investigating the first objective of this research; improving conventional urban planning in Cairo which is illustrated at the end of this chapter in terms of the combined passive design tools and methodology (Fahmy and Sharples 2008c; Fahmy and Sharples 2009a).

2.2 Site selection:

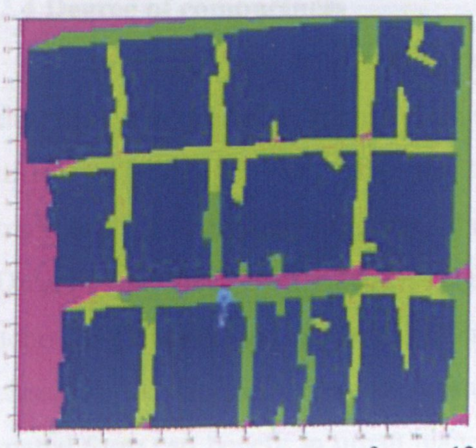
Despite this pre-planning method of selecting an appropriate climate conditions through selecting a specific site is crucial, but it hasn't been included as a passive tool in this research as case studies assessed are already exist. The importance of considering site selection as passive tool came for example from the need to study water resources and management which decide the technology of irrigation and drainage systems for green ground coverage in semi-arid climate like Egypt. However, there is a wide range of green coverage plantations that cope with the arid climates which is characterized with the low rate of water consumption, bearable to salty soils and hot climate (Snyman 1998; Schenk and Jackson 2002; Kotzen 2003).

Site selection studies support evaluation of the factors that may affect the continuity and deliverability of the community infrastructure and facilities to the next generations with regard to the sustainability concept itself (Brundtland 1989). Global Information Systems (GIS) and satellite imagery showed much to support site selection with regard to soils, (Facchinelli et al. 2001) and neighbourhood needs (Elwood and Leitner 1998). Moreover, GIS offers geo-environmental land use planning support (Dai et al. 2001), so that many aspects can be gathered in the preplanning stage as follows:

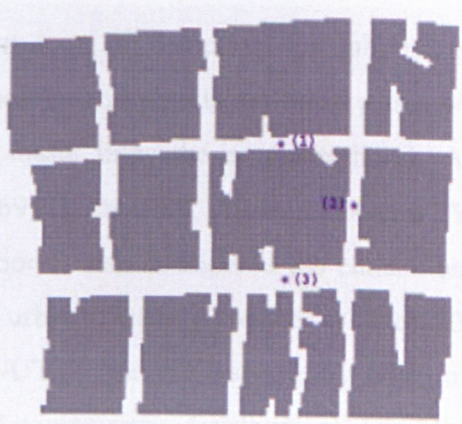
1- Natural resources of water, minerals, building materials...etc.
2- Feasibility of international, national, regional, and local networks and transportation alternatives.
3- Utilities such as sewage and drainage.
4- Environmental impact assessment.
5- Site relation to the national and international ring of earthquakes and volcanoes.
6- Climatic data survey.
7- Topography, slope and levelling details of the site to support urban form alternatives' design.
8- Thematic mapping for the surface temperatures and UHI to help future urban planning climate based and energy saving developments.

2.3 Urban pattern type:

Urban patterns types have a mutual effect with the climatic conditions due to fabric spatial distribution that influence radiant exchanges as well as wind within the canopy layer and outline the importance of initially defining the pattern type by which a master plan sketch design begins (Moughtin 1992; Moughtin 2000). Therefore, an understanding of different patterns effects is basic. Different comfort effects of different forms in Cairo demonstrated by (Fahmy and Sharples 2008c) and found that the more compactness the more comfortable, which is in good agreement with literature (Coronel and Alvarez 2001; Jenks et al. 2002; Neuman 2005; Johansson 2006), but on other hand limits wind access, fig (2-1). In addition, form compactness increases sustainability in terms of short travels from within neighbourhood parts (Ewing et al. 2007) and closing to pedestrian comfort (Ali-Toudert 2005). Moreover, (Marshall 2008) investigated urban sprawl first addressed by (Duany et al. 2000) in terms of vehicle travels and energy demand which in turn increases climate change effects and approved that more compactness. In this context, to assess the suitable pattern type and its urban morphology, an easy to use method presented by (Ratti et al. 2003; Ratti et al. 2005) revealed the Digital Elevation Model, DEM which is a process to combine digital images that contain different environmental data, but it needs access to more than one method to measure environmental data such as solar radiation, energy consumption and the sky view factor.

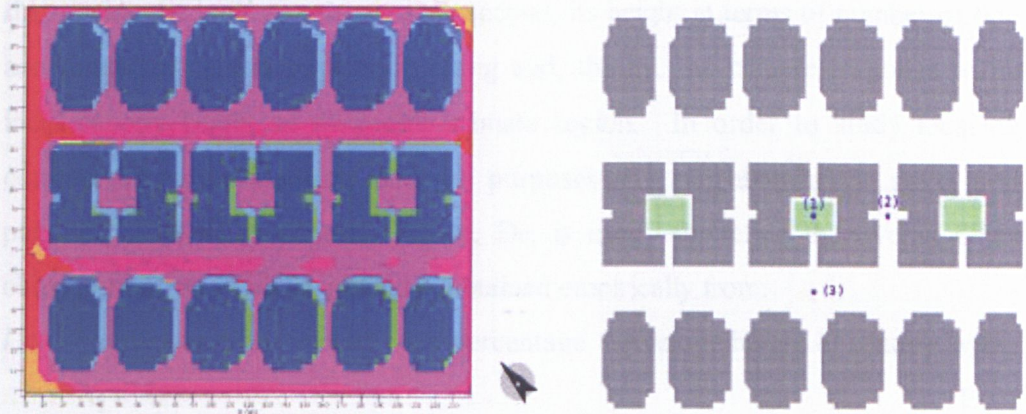


(a) PMV mapping for the compact form at 12.00 LST.

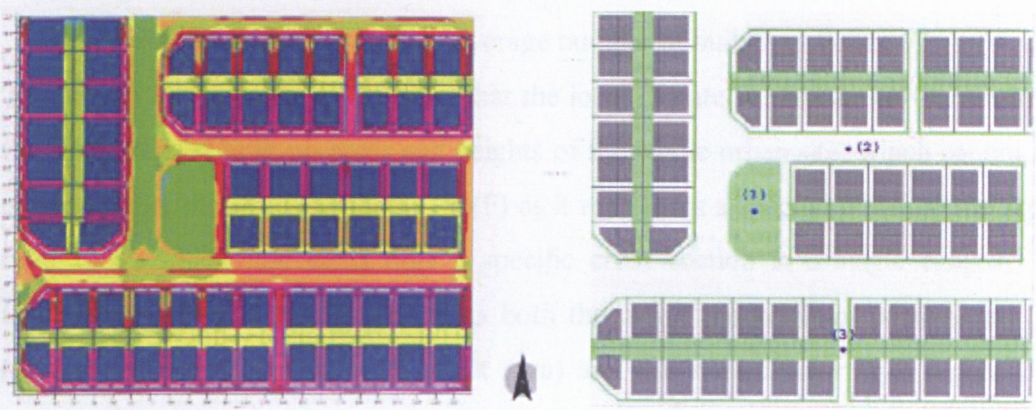


(b) Compact form master plan

Figure (2-1): *Left; PMV key for (a), (c) and (e) whereas right; (b), (d) and (f) are master plans drawn in e grey colour for buildings and the green for grass.*



(c) PMV mapping for Clustered form at 12.00 LST. **(d)** Clustered form.



(e) PMV mapping for dot fabric form at 12.00LST. **(f)** Dot fabric form.

Figure (2-1): Continued.

2.4 Degree of compactness

In completion with setting a pattern type, a definition for fabric spatial distribution is needed in terms of housing typology and population density as a while urban form design data entry for the city basic unit, the neighbourhood. As a traditional planning unit of a city, (Jacob 1969; Birch 1980; Allam and Geith 1995; Duany et al. 2000; Duany 2002), neighbourhood is also considered the climate based adaptive planning unit of the city. From an urban climate perspective, (Oke 2006) classified the city into 5 zones from UTZ1-UTZ7 but did not specify how urban spatial form can benefit in urban planning and communities development. In addition, (Duany 2002) classified the city from a Transect perspective into 5 zones from T1-T5 but did not demonstrate how traditional neighbourhood developments can address different climates. the degree of compactness, *D*c has been introduced by (Fahmy and Sharples 2009a) as an intermediate parameter for climate based urban planning that give classification of a city from. It represents three parameters; first, the population that decide the built up area as well; second, its height in terms of number of floors to accommodate certain population along and, thirdly, the climate response within the local canopy height of a specific climate region. In order to study local climate comfort for urban planning land use purposes at a neighbourhood scale, a simple parameter, the Compactness Degree, Dc, is used to define the overall degree of compactness of an urban site and is obtained empirically from:

*D*c = Total local urban construction percentage × Average height of canopy layer

$$= A_g \times A_z \qquad \text{Eq. 8}$$

Where; A_g is the constructed urban area (m^2).

A_z is represented in terms of average number of buildings' floors.

The reason for having such factor is that the local climate studies do not parameterize the differentiated built up areas and heights of the whole urban site, which cannot rely only on either the sky view factor (SVF) as it represents a specific point, or the aspect ratio H/W, which represents only a specific cross section in a single canyon. The Compactness Degree factor represents both the urban ground floor constructed area (or the land bearing capacity for built area) and the local canopy layer height Z_h in terms of the average number of floors. For example, the first case in (Fahmy and Sharples 2008c) had a Dc of 0.683 × 5 = 3.415, that means if Dc equals the average dominant number of floors in a built up urban area, the compactness degree is a maximum for this local urban area and vice versa. By this way, different city zones can be classified into 5 degrees (D1: city centre = very compact, D2: central urban = compact, D3: general urban = medium, D4: suburban = open, and D5: rural urban = very open). Consequently, each local scale and in turn city landscape can have different urban forms despite having the same compactness classification.

2.5 The Greensect:

As a conclusion of the work done by (Duany et al. 2000; Duany 2002; Fahmy and Sharples 2008a; Fahmy and Sharples 2009a), the *GreenSect* (*Green* coverage within city tran*Sect*) is a passive urban planning tool that can be defined not only as a hierarchy of passive techniques (urban tree shading, evaporation from green surfaces, and nocturnal cooling nodes) but also as an urban pattern structure that has parks and gardens regularly distributed along the city urban zones from the urban core to the rural urban reserve. The main drivers for this study were: (i) the increased risk of thermal discomfort for future climates in local urban heat islands where particular urban planning features exacerbate local heat emissions; (ii) the lack of a code or manual for green coverage distribution for Egyptian urban planners that would help develop and implement green mitigating features in the design of local communities. Urban planning theories define public green and vegetated as a land use percentage area that has to be considered, because "parks and green areas are known to create park cool islands (PCIs)" (Saaroni and Ziv 2003). PCI intensity ranged 3-5°C in Sacramento (Spronken-Smith and Oke 1998), and the green coverage is thermally valuable regardless of climatic region (Roth 2007). Cooling effect from shading decreases the energy demand for mechanical cooling in the day time and stimulates nocturnal cooling effect (Waziry 2004), but depends on the open area exposed to open air (Rosenfeld et al. 1995). This is very effective in residential areas (Huang et al. 1987) where breezes from parks to the nearby building fabric can be generated not only for cooling (Eliasson and Upmanis 2000) but also to improve air quality (Akbari et al. 2001). Parks and open spaces have a role in increasing health quality, thermal stress reductions and aesthetic benefits (Murakami 2006), have their impact in reducing the noise effect (Lam et al. 2005; Gidlof-Gunnarsson and Ohrstrom 2007). Consequently, different scales of parks can modify the atmospheric conditions in the surrounding neighbourhoods (Oke et al. 1989; Spronken-Smith and Oke 1998; Spronken-Smith and Oke 1999; Yu and Hien 2006). Scales of parks and gardens are related to the planning communities' scales, i.e. city has to have its park/s, town has to have its park/s, community/district has to have its park/s, neighbourhood /village has to have its garden/s, each group of buildings blocks has to have its garden/s, fig (2-2 /b, c, d) which introduces a shape of cooling node networks all over the urban planning community. In addition, it stimulates the built environment psychological adaptation for human comfort (Nikolopoulou and Steemers 2003; Matsuoka and Kaplan 2008). Dimensions of the park have to be 2.2-3.5 the height of the border trees at minimum (Chudnovsky et al. 2004), and (Barbosa et al. 2007) statistically discussed the distances towards the nearest public green area in Sheffield, but did not give an explanation on how green structure can be related to master plans.

Left; Figure (2-2/ a): Each urban planning level has to have its efficient park/garden area which is continued as a chain from the urban core to building block level, Karlsruhe, Germany, adapted from Google images.

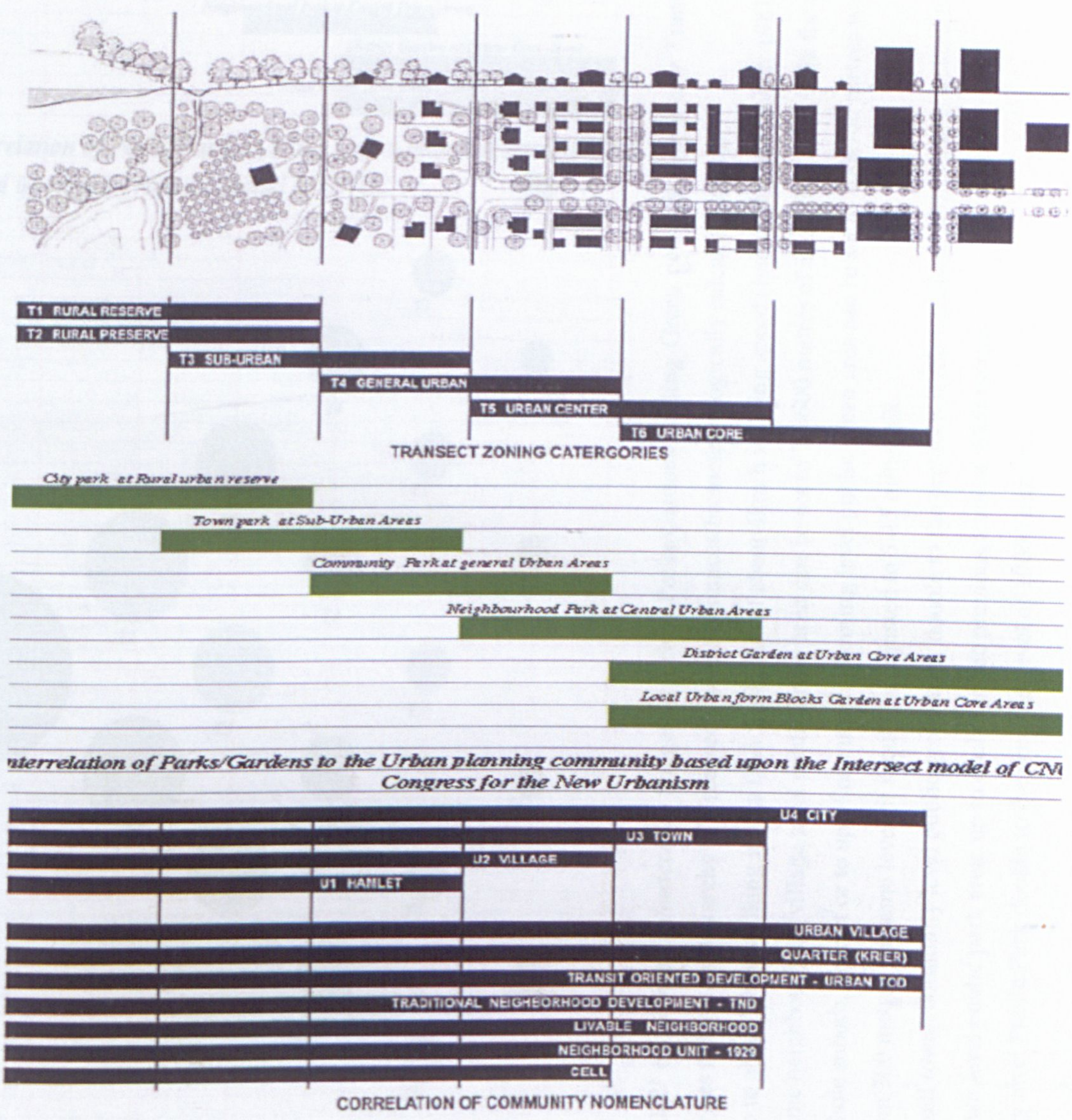


Figure (2-2/ b): Urban green scheme of parks and garden within urban planning community presented on the Transect (Duany, 2002) model of new urbanism, Congress for New Urbanism, CNU.

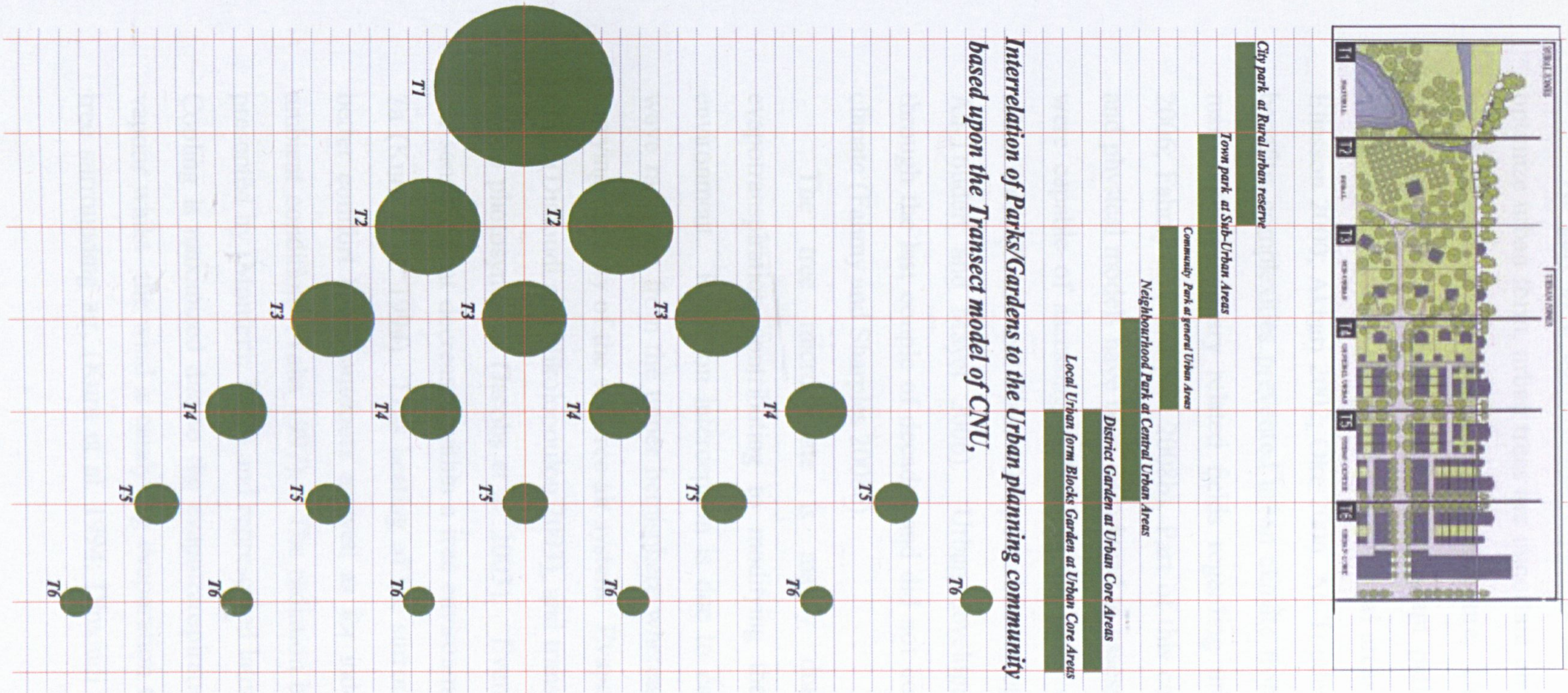


Figure (2-2/ c): ***Urban Greensect;*** A Suggested Urban Parks/Gardens cooling Green network over a city Transect, i.e. each urban planning level on the transect of a town/city has to have its hierarchy of Greensect, where distances biometeorologically calculated up to:

1- Up to about 300m walking in less than 5 min due of about 4km/h walking speed (Jendritzky and Nübler 1981; Jiang 1999; Duany 2002) is for an urban cluster garden.
2- Same neighbourhood/village level public green area can be set to 70-600 metres of about 5-10 min walk for the same previous criteria.
3- Whole suburb, district or to up of one urban planning level public green area can be set to 300-900 metres walking, i.e. regardless (Barbosa et al. 2007) has mentioned from 300 metres for same level, it should be adjusted to 5-15 min walk.
4- Small town/community level public green area; double to the previous level, i.e. about 2000 metres walked in about 30 min., no walking should be after this level.
5- Town level public park area; up to double to the previous level of 5000 metres.
6- City level Public Park double to the previous level of 10000 metres.

2.6 Urban trees:

2.6.1 Trees benefits:

As part of a comprehensive passive urban climate strategy, and in order to optimize urban form, urban trees are important elements of site vegetation and have to be at the core of any applied design procedure. Urban trees improve the microclimatic performance of the built environment, adapt patterns to climate change and reduce energy consumptions especially in residential areas (Oke et al. 1989; Kurn et al. 1994; Eliasson 2000; Akbari 2002; Oke 2006; Ali-Toudert and Mayer 2007b). Despite these benefits, complexities prevented urban climate from supporting the decision making of many interdisciplinary related fields regarding urban tree use, (Arnfield 2003; Oke 2006; Fahmy and Sharples 2008b). Part of this complexity is that many mathematical and physical models have been introduced to assess urban thermal interactions, but few were capable of assessing sufficiently the many details of urban elements including urban trees (Bruse and Fleer 1998; Pearlmutter et al. 1999; Shashua-Bar et al. 2004; Ali-Toudert and Mayer 2006). Urban developments in Cairo were overwhelmed through the last couple of decades and did not consider urban trees to control its hot climate (Fahmy and Sharples 2008c).

The tree microclimate is mainly due to intercepted radiation and evapotranspiration contributing to modifying the heat balance of the surrounding environment. Radiation interception is due to canopy prevention of short and long wave radiation from the upper hemisphere whereas evapotranspiration is due to water carrying capacity of the soil-tree-air system. Evaporation takes place from leaf surfaces to air (Dimoudi and Nikolopoulou 2003), and transpiration from soil through leaf stems due to photosynthesis (Jacobs et al. 2003). Eventually, the latent heat increases and the sensible heat decreases within a tree environment leads to a lower air temperature Ta (Kurn et al. 1994). Less heating of the surrounding air is then achieved, meaning better comfort levels outdoors as well as for indoors due to the modification of the ambient conditions (Taha 1997). The radiation balance that a tree modifies was first presented by (Monteith 1973) and represented later by (Oke 1987; Sailor et al. 2008a). Cooling is maximized due to the evapotranspiration effect of a tree due to its water vapour whilst the wind is catalyzing evaporation that is considered evaporation of the tree surrounding air, (Kurn et al. 1994; Dimoudi and Nikolopoulou 2003). Thus, the composition of urban tree canopies can help in urban passive cooling both at the micro and local scale. evapotranspiration of some plants is studied by (Jensen and Haise 1963) and found it can be calculated as following:

$$ET_c = K_c \times ET_0 \qquad \text{Eq. 9}$$

Where;

ET_c is the evapotranspiration of a crop c ($mm.day^{-1}$).

K_c is a *decimal factor* representing a crop coefficient.

ET_0 is the potential evapotranspiration of a reference vegetation, ($mm.day^{-1}$) derived from the regression equation of (Jensen and Haise, 1963) :

$$ET_0 = (0.0252T_a - 0.078).(1-a).I \qquad \text{Eq. 10}$$

Where;

I is the incident solar radiation upon crop ($W.m^{-2}$).

a is a *decimal factor* for the crop or vegetation albedo; reflectance.

T_a is the air temperature ($^\circ C$).

Nevertheless, urban trees have also more than the thermal benefits, Yoshida et al., (Yoshida et al. 2006) demonstrated that parks and vegetation have an excellent role in increasing health quality and thermal stress reductions. Contrary, microclimate wind speed reductions is a disadvantage for urban trees, especially when gathered in groups due to the drag force of plant canopies (Dimoudi and Nikolopoulou 2003; Thorsson et al. 2007) if compared to open land wind speeds (McPherson et al. 1997). Another disadvantage is the diurnal patterns of warmer night time temperatures and cooler daytime temperatures due to the trapped heat and humidity within the urban canopy layer when compared with the rapid nocturnal cooling of open areas (McPherson et al. 1997).

Urban trees improve outdoor spaces, place making and spatial format, order, harmony, contrast, scale, proportions and variety which all can be attributed to trees urban arrangements and its geometric characteristics (Arnold 1980; Trowbridge and Bassuk 2004). Figures (2-3 to 2-6) show some tree benefits as discussed in this section.

2.6.2 Trees canopies

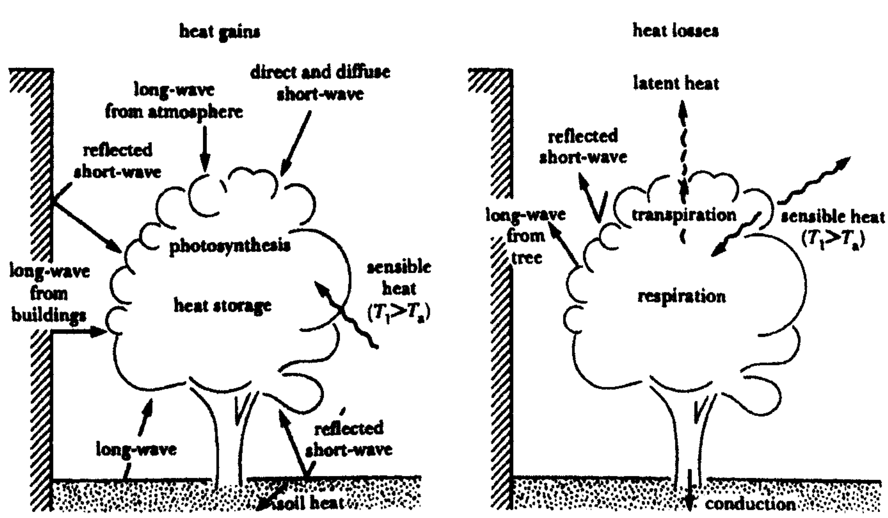
The selection of urban trees to accomplish specific urban design criteria can be based on many aspects, such as its thermal performance which in turn depends on foliage characteristics as well as tree shape; i.e. total height and canopy geometry. In addition, botanical aspects decide the selection of a tree to be planted in a specific site; i.e. type of soil to be planted in, tree deciduousness, depth and radius of roots, capability of bearing site hazards and harsh climates (Arnold 1980; Trowbridge and Bassuk 2004).

Leaf area density, *LAD* and leaf area index, *LAI* are conceptual environmental canopy modelling parameters for studying tree heat exchanges with the environment as they have significant role in urban heat balances (Jonckheere et al. 2004; Montes et al. 2007). **Based on the radiation interception concept through flat leaf tree canopies, *LAI* is defined as a dimensionless value of the total upper leaves area of a tree divided by the tree planting ground area** (Jonckheere et al. 2004; Shahidan et al. 2007). By definition, 100% of direct solar radiation interception means that canopy shadow should equal ground planting area. In this respect, *LAI* for the same tree could vary from one season to another by virtue of the tree being deciduousness or from age and growth stage, and so there is still the chances to propose other definitions and interpretations of *LAI* (Jonckheere et al. 2004). ***LAD* is the key parameter needed to model the radiation through a tree canopy and between a tree and its environment. It can be defined as the total leaves area in the unit volume of a tree horizontal slices along the height of a tree that can give an idea about the vertical leaves distribution** (Meir et al. 2000; Law et al. 2001b). *LAD* modelling can be estimated by means of field measurements manually or using instrumentations along with empirical models (Jonckheere et al. 2004). For example, Meir et al. (Meir et al. 2000) investigated tropical trees estimations by a photographic method. The Beer–Lambert law (which relates the absorption of light to the properties of the material through which the light is travelling) was used to calculate *LAI* using the extinction coefficient and the measured light transmission (Pierce and Running 1988).

Trees 3-D profiles were described by (Stadt and Lieffers 2000), but for limited specimens and their MIXLIGHT model could be complicated in application whereas an empirical method derived by (Lalic and Mihailovic 2004) to model *LAD* if the maximum *LAD*, L_m, is known which in turn is calculated in terms of *LAI*.

Beer–Lambert law which relates the absorption of light to the properties of the material through which the light is travelling, was used by Pierce and Running (Pierce and Running 1988) to calculate *LAI* using the extinction coefficient and the measured light transmission. *LAI* can be measured, manually or by instruments, for example (Kotzen 2003) used a scanner for *LAI* measurements, whilst the Plant Canopy Analyzer (type Licor LAI-2000) and many ways are reported by others (Stadt and Lieffers 2000; Jonckheere et al. 2004; Shahidan et al. 2007).

LAI investigations for tree modelling in hot regions have lacking studies either from a measurement point of view or from a modelling point of view. The study of (Kotzen 2003) in arid regions and the (Shahidan et al. 2007) study in a hot humid region are two of the very few examples in comparison with other climate regions and forest tree studies (Meir et al. 2000; Stadt and Lieffers 2000; Jonckheere et al. 2004). In addition, urban tree modelling to assess their thermal effects on buildings in hot regions are even sparser.



Scheme of the daytime energy exchanges between an isolated tree and its street canyon environment. (T_l, T_a, temperatures of leaf and air.)

Figure (2-3/a): Thermal behaviour of trees, adapted from (Oke et al. 1989).

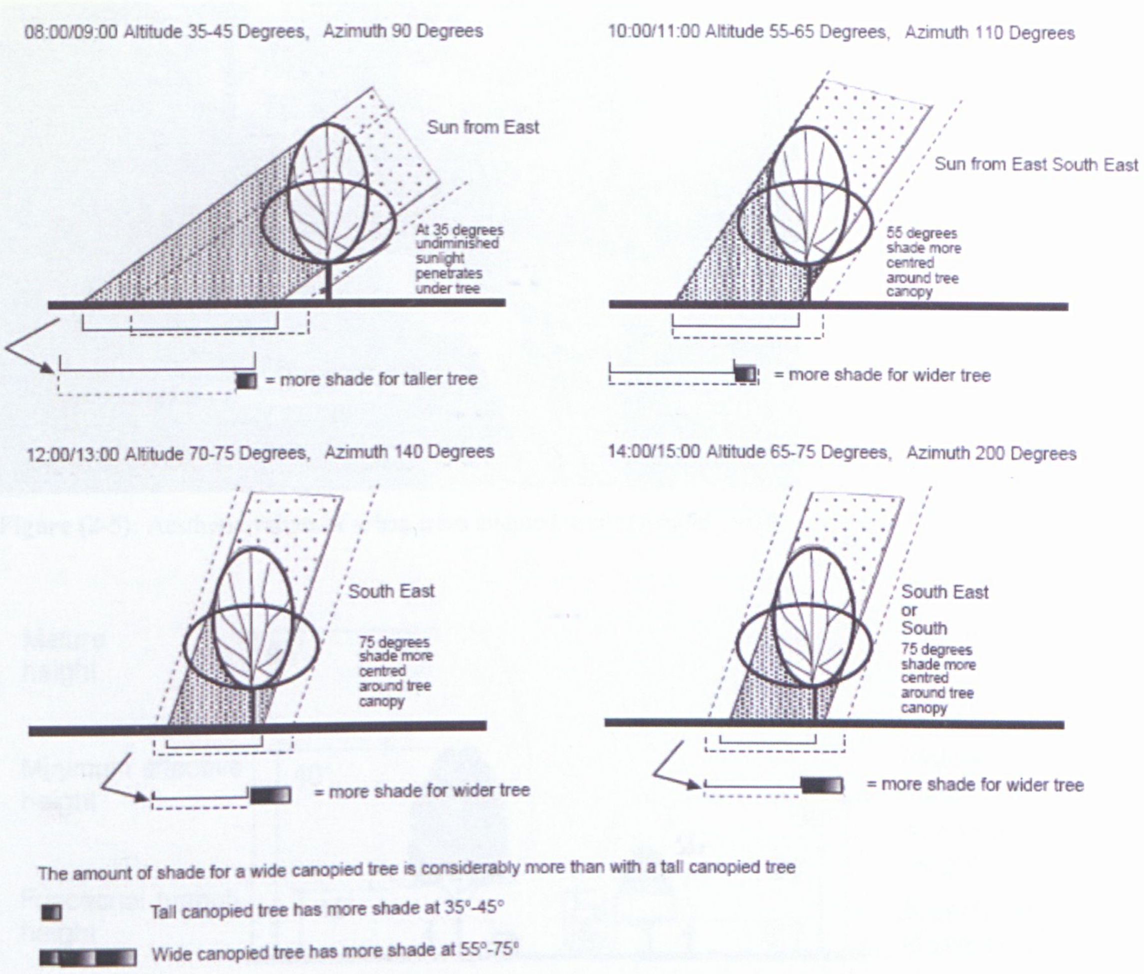


Figure (2-3/b): Trees shading comparison created by broad/wide canopied trees in contrast to tall canopied trees, adapted from (Kotzen 2003).

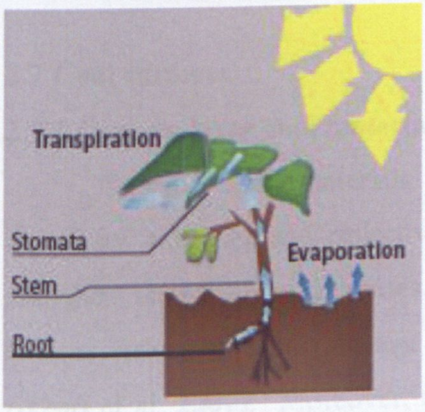


Figure (2-4): Evapotranspiration process, adapted from (EPA 2009d).

Figure (2-5): Aesthetic values of urban trees adapted from (Arnold 1980).

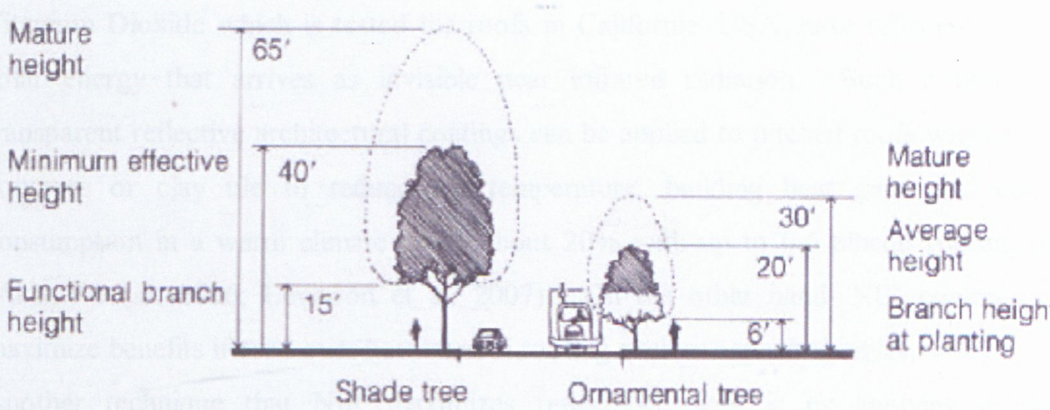


Figure (2-6): Mature tree geometry, adapted from (Arnold 1980).

2.7 Cool surfaces

2.7.1 Canopy layer cool materials

Canopy layer materials include pavements, walls and roofs. As material emissivity increases and reflectivity decreases, more sensible heat gain is introduced and then temperatures increases. Urban canyon surfaces with high albedo and light colours reduce the heat storage in the materials (Rosenfeld et al. 1995; Taha 1997; Akbari et al. 2001). Moreover, if roof and pavement albedo increased by about 0.15-0.2, a global cooling counter affect for the global warming and GHG might take place as roofs and pavements area measure about 60% of the urban surfaces area, (Akbari et al. 2009).

The effect of colour and composition of roof tiles and pavements have been studied by (Akbari et al. 2006; Levinson et al. 2007) in order to encourage the UHI mitigation methodologies by increasing the overall albedo and decreasing asphalt and paved area. Measured data reported by (Akbari et al. 2001), indicated that increasing pavements albedo by 0.25 decreased pavement temperatures by 10°C. The definition of cool pavements has been expanded to include permeable material that allow penetration of moisture and air to increase cooling effects (EPA 2005). The Berkeley laboratory of the University of California in cooperation with partners developed cool non-white colour materials combines both high solar reflectivity and different colours in order to avoid potential glare and to provide more market aesthetic values (Akbari et al. 2006). These are the near infrared (NIR) spectrum coatings such as Chromium Oxide and Titanium Dioxide which is tested for roofs in California, USA, have reflected 52% of solar energy that arrives as invisible near infrared radiation. Such a non-white transparent reflective architectural coatings can be applied to pitched roofs whether it is concrete or clay tile to reduce tile temperature, building heat gain, and energy consumption in a warm climate up to about 20% with up to 0.6 albedo roofing tiles (Akbari et al. 2006; Levinson et al. 2007). On the other hand, NIR coatings can maximize benefits if used over normal cool roofing such as asphalt shingles.

Another technique that NIR maximizes reflectance with is by applying a weak absorbent that scatters NIR radiation at the topcoat such as pigments and adding an NIR-reflective basecoat such as Titanium Dioxide white (Akbari et al. 2006).

These cool surfaces approaches were estimated to save about 400 million US$ if applied in the surveyed 11 US cities (Konopacki et al. 1997) and more savings has been extended using a combination of cool surfaces and shade trees by (Akbari and Konopacki 2005).

2.7.2 Green roofs:

Generally, cool surfaces are characterised with high albedo despite their color. But, as vegetation is characterized with its permeability, evapotranspiration effects and wet surface which all increase the latent heat and reduces sensible heat (Santamouris et al. 2007; Sailor et al. 2008a), it can be then considered a *cool surface* as described by (EPA 2005; EPA 2009c) despite its albedo values are considerably less in comparison with *cool materials*. That is why it is commonly used in some countries along with other shading vegetation types as intensive green roofs (EPA 2009c; EPA 2009d). Studies of green roofing as cool surfaces found that using them in bigger areas over cities can significantly contribute to UHI and climate change mitigation along with energy saving (Akbari 2002; Sailor and Dietch 2007; Santamouris et al. 2007; Alexandri and Jones 2008; Sailor et al. 2008a; Sailor 2008b; EPA 2009c; EPA 2009d). In addition, it contributes to tackling the environmental degradation and urban decline of green coverage that has health and psychological effects (Carter and Keeler 2008). Figure (2-7) illustrates how green roofs can be applied together with residential areas backyards to maximize cooling effects.

Figure (2-7): A combined passive techniques; array of green roof with a remarkable green back yard in completion with adjusted fabric form and orientation, adopted from (Herzog 1996).

2.8 Summary

This chapter has presented some tools that can be used on a local scale for urban climate based planning regardless of the passive techniques applied. Some of these tools can apply to one or more of the passive techniques, which are mainly solar sheltering, ventilation and evaporation.

Urban passive cooling tools are not the cooling techniques such as shading, evaporation or ventilation or their applications by the usage of different fabric details, orientation, and vegetation or water sources. They gather inputs of buildings and housing typologies, appropriate pattern type, land uses and population densities, green structure and trees arrangements so that an urban passive form designer can achieve some degree of local climate control and within which passive applications are used to achieve a so called urban passive cooling system.

Urban passive tools can be grouped into three groups; firstly, pre-planning and design stage tools such as site selection. The second group is concerned about the fabric, the buildings themselves, how they can be formulated using the pattern type and degree of compactness which can be considered the adaptor of the fabric form. The Urban GreenSect, is a green structure based on the human biometeorology, is considered one of the main tools that can help in directing the land use, zoning and the initial neighbourhood sketch design towards specific urban form instead of just planning to accommodate population. Urban GreenSect and urban trees are the third group of tools to design a passive form. Finally, using cool surfaces, including green roofs, is the fourth group which doesn't affect the form itself rather than improves outdoor conditions.

Chapter three: empirical urban passive structures

3-1 Introduction

For an urban development to be planned and constructed in the time of climate change specifically in a hot region, it is not sufficient to handle it conventionally without climate considerations (Givoni 1998). At the same time a proposed improvement for urban development in Cairo has to be investigated, a reference to its urban planning background has to be considered because any generated land use, master plan and urban form is a direct conclusion of urban planning literature whether it is climate based or not. This might be the lost connection between climatology and an applied practice as both disciplines practice work in different ways due to their separate education as reported by (Eliasson 2000), the former is almost engineering with quantitative approaches while the latest is humanities with qualitative approaches. In addition to all quantitative inputs influence neighbourhood site planning, other qualitative inputs have the same importance for the urban spaces (Cullen 1961; Jacob 1969; Lynch 1981; Bentley et al. 1985; Bentley 1999). Therefore, an urban passive form designer has to be aware of both disciplines data entry for local scale as proposed in fig (1-9). Moreover, Egyptian urban planning law (Law3 1982) and its development in 2007 still depend on the western theories for urban planning and development in terms of the neighbourhood concept particularly in Cairo since more than 100 years without developing an appropriate neighbourhood form to cope with its climate (El Araby 2002; Fahmi and Sutton 2008). With respect to neighbourhood platform as an urban unit for the city, there is no definite area for a neighbourhood; it can be defined through the concept of a 5-10 minutes walk from its border towards its civic centre and can be defined with relation to the city utilities or separately. Therefore, an investigation for the present applied urban planning theories and movements along with historical neighbourhood examples demonstrated in this chapter was a necessity to know how urban designers think and how a spatial structure can be formed. Then this chapter analyses the vernacular urban architecture preceded the last century of western urban planning practice in Cairo. Such an important period of time lasted from the medieval ages until before the last 100 years (discussed eventually in chapter four) had to be analysed as it experienced the most world wide known compact urban architecture. This analysis revealed using the clustered form over a basic neighbourhood in a pilot study to ensure the research main methodology in terms of a proposed passive system, spatial form and fabric unit before going forward with the bigger neighbourhood scale in chapter five.

3.1.1 Review for Urban planning renaissances:

The progress of human settlements and communities has passed through several stages in history that can be classified and called the urban planning renaissance movement.

First urban planning renaissance movement; this occurred in the ancient ages of humanity when the human settlements transferred from disparate nodes to small towns or villages like Babel, Rome, Tiba (Luxor)...etc. Some of those historic communities are still surviving today (Lynch and Hack 1984).

Second urban planning renaissance movement; conflicts in the pre-medieval and medieval ages of humanity helped in the formation of states. This period can be described in terms of historical ideological city planning based on political or political religious ideas and helped form many of the civilized world's national communities that are almost continuing to the present. The neighbourhood concept is not a new one. In fact all of the ancient communities were neighbourhood villages or small towns that had their service centres - Rome around the Forum, ancient Fatimid Cairo around two parallel main roads (with the governor's palace and the mosque in between them), Damascus and the ancient great Baghdad around the great mosque are examples. Historical planning applied the social levelling or job kind as a division method for town parts or units.

Third urban planning renaissance movement; this was the early Classic planning dreams of modernism and classic planning theories from the 19th century to the 1930s of the 20th century. Coastal linear, central radial, organic or modular, garden and industrial, functional and social city planning concepts were the dominant concepts depending on the thoughts of the architects (Allam and Ghaith, 1995). The development sequence for the neighbourhood concept was as follows:

1- The increased population and industrial activities led to a social revolution towards workers rights and led to the first form of a new neighbourhood type:

a- In England, for example, Saltaire (1852) was a textile factory and the owner built a 3000 worker residential community near Bradford (Allam and Geith 1995; Neal 2003). In 1848 James Buckingham planned a 5000 worker community, and in 1886 the Lever brothers, soap factory owners, built Port Sunlight near Liverpool.

The Garden Town planning trend was introduced by Ebenezer Howard (Howard 1902), fig (3-1), and was responsible for about twenty cities were founded upon the Garden Town idea in the UK.

b- In France, a pioneer project by architect Tony Garnier for an industrial city close to Lyon was to have 35,000 citizens based upon city zoning. In Germany, the crop foundation established a workers' village near Essen city, (Allam and Ghaith, 1995), followed by the new towns in East Germany after World War II. The roots of socialist urbanism in the Bauhaus have stressed the importance of modern town planning. In the Soviet Union when the socialist concepts of modern urbanism evolved the great strategy of founding new towns as part of the decision made in 1929-30 by famous soviet planners like L. Sabsovics to initiate massive industrialization and urbanization, (Bernhardt 2005). As a conclusion; the planning of the new town of Magnitogorsk took place in 1930.

c- Outside Europe - in Egypt Misr-Elgadida in the late 18th century and Al-Mahalla, a city north west of Cairo, had an increasing density of industrial textile activities and by 1910s many villages had been constructed by the owners of the textile factories.

2- Famous architects like Frank Lloyd Wright and Le Corbusier (Zeitoun, 1993), fig (3-2), had evolved some thoughts after the Industrial Revolution supported by symbolism, expressionism, functionalism, organism and the dominant political thoughts of that time like liberalism, economics, and socialism. Many other artistic and architectural trends and dreams in architectural design were the second factor affecting the urban planning movement and great construction projects all over the world in middle of the 20th century, especially after World War I. For example:

a- The Utopian city planning of Wright was based upon the horizontal growth instead of the vertical and on natural materials instead of concrete, fig (3-2), *Broadacre City*, part of Wright's thoughts in 1932 (Sdoutz 2009). Utopian city planning based on the centralized market and high buildings with grid networks for Le Corbusier based on the recommendations of CIAM Athens 1933 and been used to plan and build Chandigarh in India, fig (3-3) (NYU 2009).

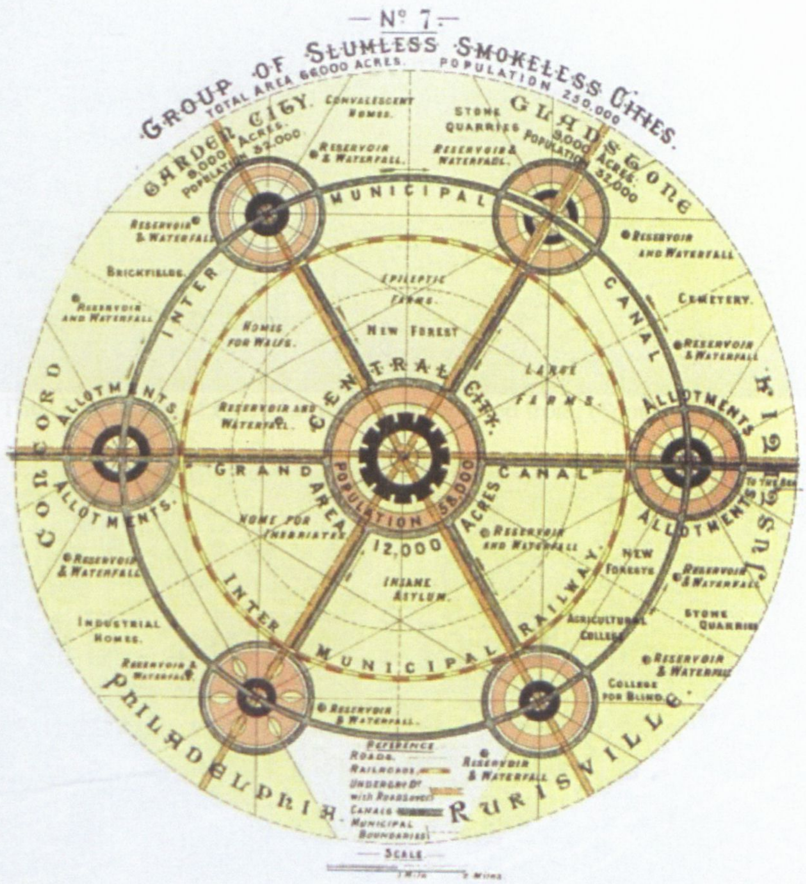


Figure (3-1): Ebenezer Howard Garden city as diagram not a plan, adapted from (Howard 1902).

b- In 1923 the neighbourhood had a chance to be applied practically and to act as the fundamental planning unit when Perry suggested the neighbourhood to be a unit planning, fig (3-4/a). The Garden City concept transferred to Europe and the USA as a garden suburb form and had an effect on many planners. In 1924 Henry Stein and Clarence Right, who had studied the Super Block idea of Le Corbusier within the garden idea, planned a suburb called Sunny Side near Manhattan of New York for workers.

In 1929 the RadBurn Town by Henry Stein and Clarence Right, 28 kilometres from New York, was another application of neighbourhood planning as a conceptual unit for planning, figure (3-4/b).

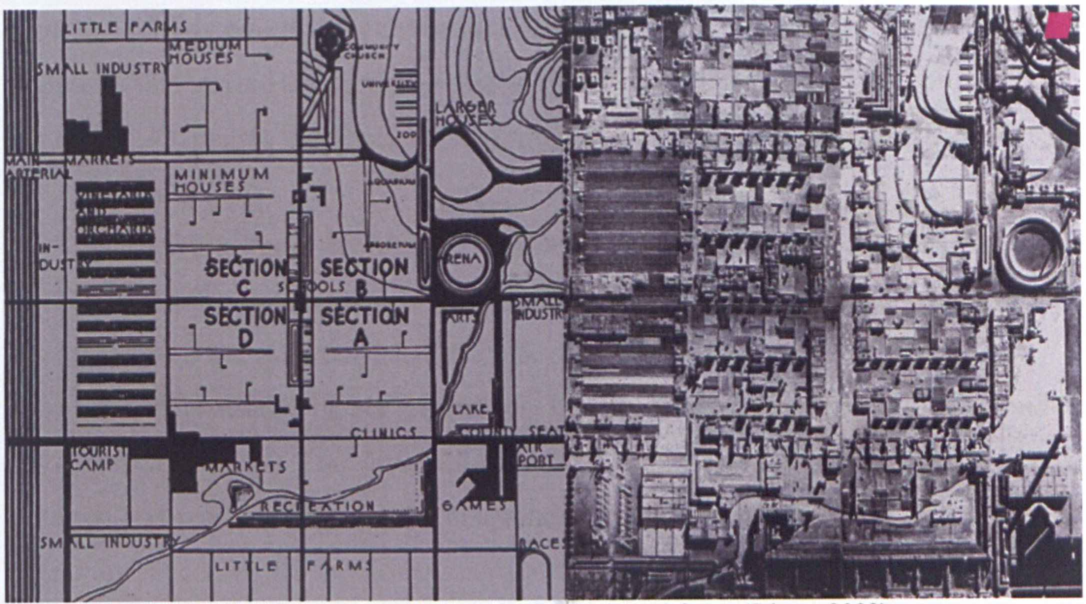


Figure (3-2): The Utopian city of Frank Lloyd Wright, adapted from (Sdoutz 2009).

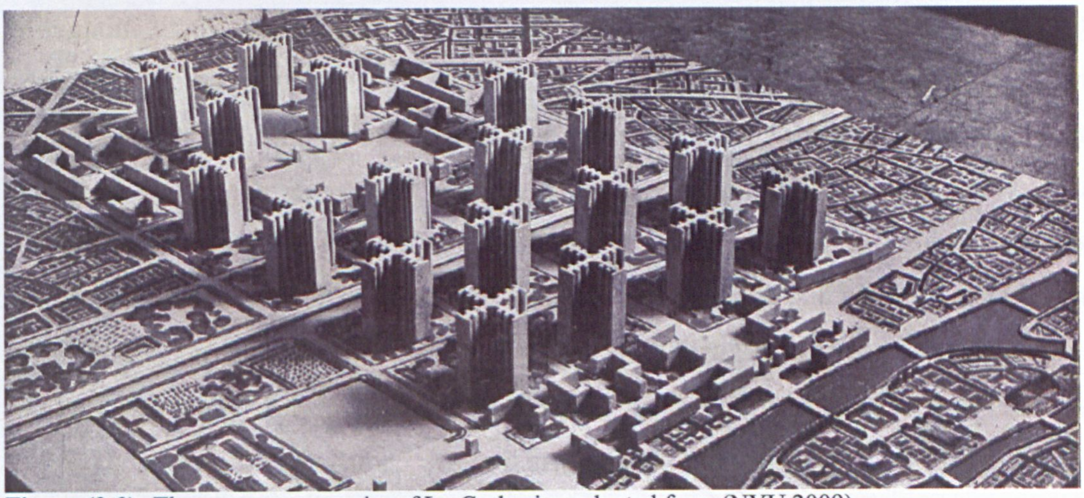


Figure (3-3): The contemporary city of Le-Corbusier, adapted from (NYU 2009).

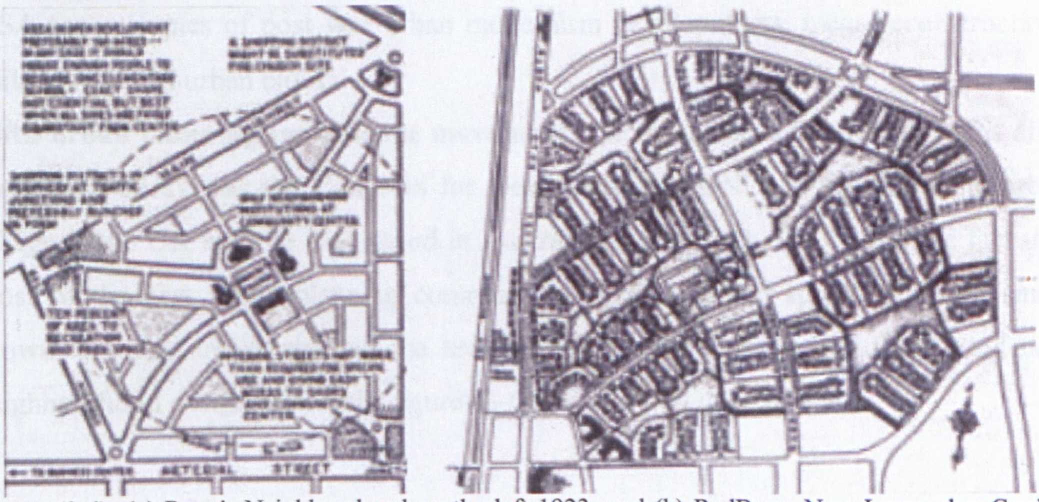


Figure (3-4): (a) Perry's Neighbourhood on the left 1923, and (b) RadBurn, New Jersey plan Garden Town by Henry Stein & Clarence Right 1929, adapted from (Lang 1994).

Fourth urban planning renaissance movement; the most historical groups of architects that started the urbanism dogma of the world were:

1- CIAM, "Congrès Internationaux d'Architecture Moderne", (Bullock 2002; Silva 2003; Gold 2004).
2- The Socialist Party of Modern Urbanism, which was a non-formal association based on the Soviet party's thoughts and urban recommendations, (Ladd 2001; Mumford 2002; Andrusz 2004; Bernhardt 2005).

CIAM had the bigger effect due its manifesto being transferred beyond the European continent. The great effect CIAM made was the start of Urban Design research and applied work for the first time when the Latin expression **Urbanisme** had been introduced despite the expectations at that time that it wouldn't be accepted by the public. Nevertheless, rethinking of the urban political strong relationship, (Gill 1994; Moughtin 2000) improved methodologies and the generation of urban forms. By comparing between the socialist and the western model of urbanization, it can be claimed that the future failure of similar urban planning policies in a single party governed country is expected. On the other hand the suburban community urban planning policies in the western model of planning resulted in great urban sprawl case studies, especially in countries that had high national incomes and high populations and were far away from the European source of the early urbanism waves. Those countries, like the USA and Canada, had the most urban sprawl (Duany et al. 2000; Tsenkova 2004; Tsenkova 2006). Robert Moses' mega renewal projects in the USA, fig (3-5), Nasser City place in Cairo 1960s and the great Suburban movement of the 1960s in USA are examples of post war urban modernism developments, mega reconstructions and renewal and urban blocks.

Fifth urban planning renaissance movement; the most influential urban groups after the CIAM decay was the Congress for New Urbanism, CNU, in the USA, the urban village in the UK and the Livelihood in Australia (Neal 2003). They faced the fact that most of the new urban planning communities were suburban sprawl affecting smart growth patterns and decreasing the level of sustainability of cities and proposed new neighbourhood design principals; figure (3-6).

Figure (3-5): Rebuilding plans for Washington Square and six other New York sites were drawn up by Robert Moses' Committee on Slum Clearance 1949, adapted from (Laurence 2006).

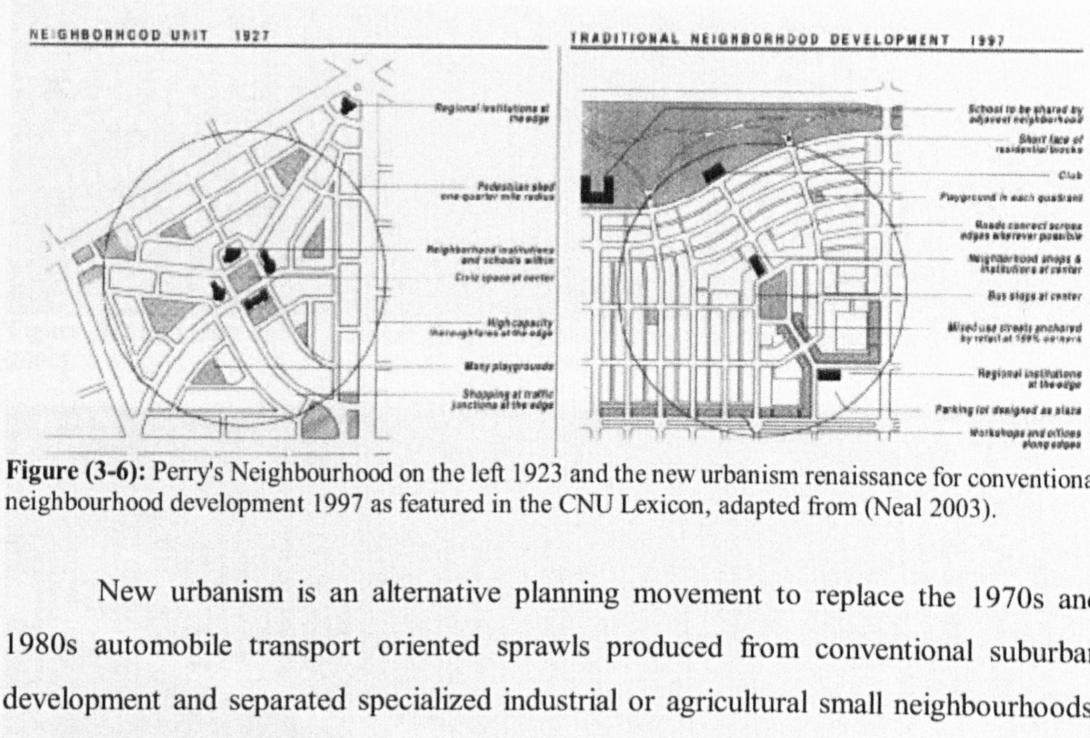


Figure (3-6): Perry's Neighbourhood on the left 1923 and the new urbanism renaissance for conventional neighbourhood development 1997 as featured in the CNU Lexicon, adapted from (Neal 2003).

New urbanism is an alternative planning movement to replace the 1970s and 1980s automobile transport oriented sprawls produced from conventional suburban development and separated specialized industrial or agricultural small neighbourhoods, fig (3-7/a, b). The principles of CNU are:

1- the conventional neighbourhood planning concepts like:

  a- Neighbourhood has to have an inner heart of action, social and recreational and activities of civic services where buildings are close to streets.

  b- The five minutes walk from dwellings to the amenities centre of action.

  c- Shopping offices and retails at the borders of the neighbourhood.

d- Primary and nursery schools are close to children.

e- All dwellings have to have public close green area despite the private one.

f- There are ascending levels of vehicle network connecting neighbourhood to other neighbourhoods.

g- Parking areas are on the rear side of dwellings.

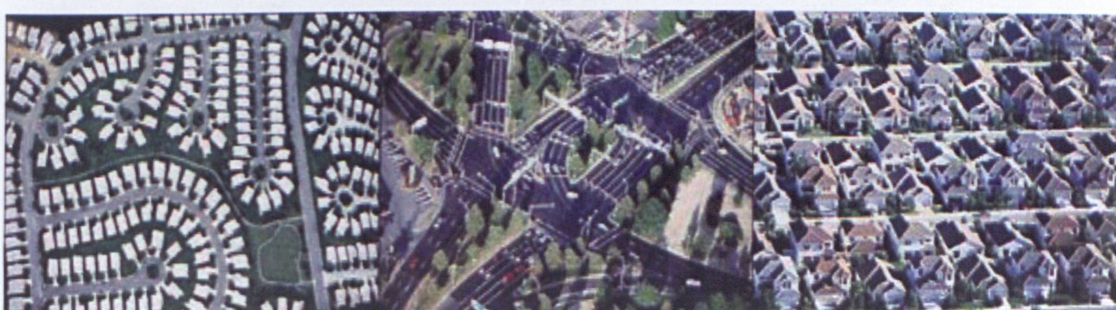
h- A chain of self government from the neighbourhood scale to the country government with local authority in between them.

2- An environmental planning vision instead of just greening and planting suburbs.

3- Mixed use streets to ensure urban regeneration of patterns for people.

4- Built environment diversity in terms of different types of housing instead of single family housing only.

5- Smart growth concept.



Figure(3-7/a): Urban Sprawl automobiles dependant planning examples, adapted from (Duany et al. 2000).

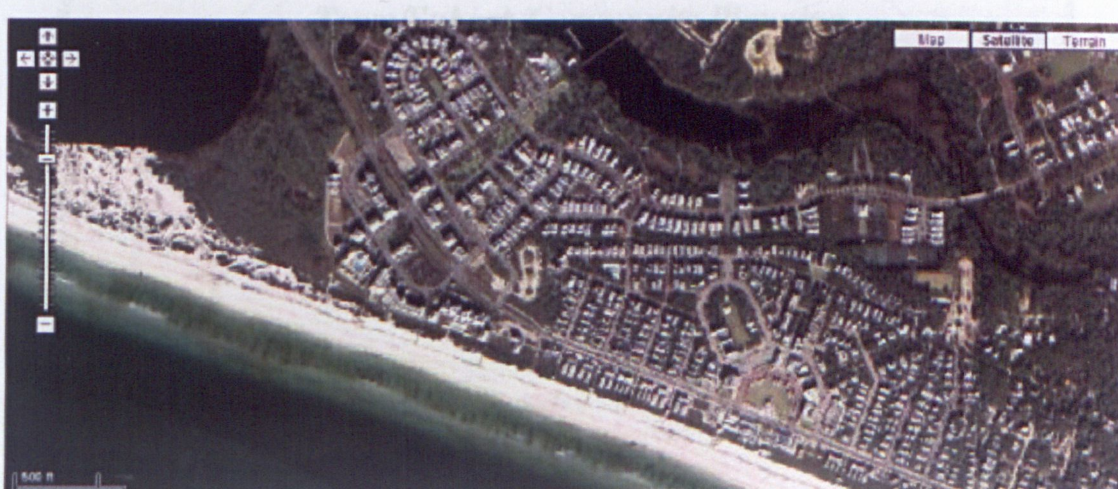


Figure (3-7/b): New Urbanism design for Seaside neighbourhood, Florida, USA, adapted from Google maps.

3.1.2 Urban design in the planning discipline.

Figure (3-8) demonstrates the chain of planning actions in respect to the size of planning community as neat placements for the urban scales into the planning process, so that neighbourhood planning can be taken in a bigger view if climate is to be considered as it is not only a neighbourhood scale.

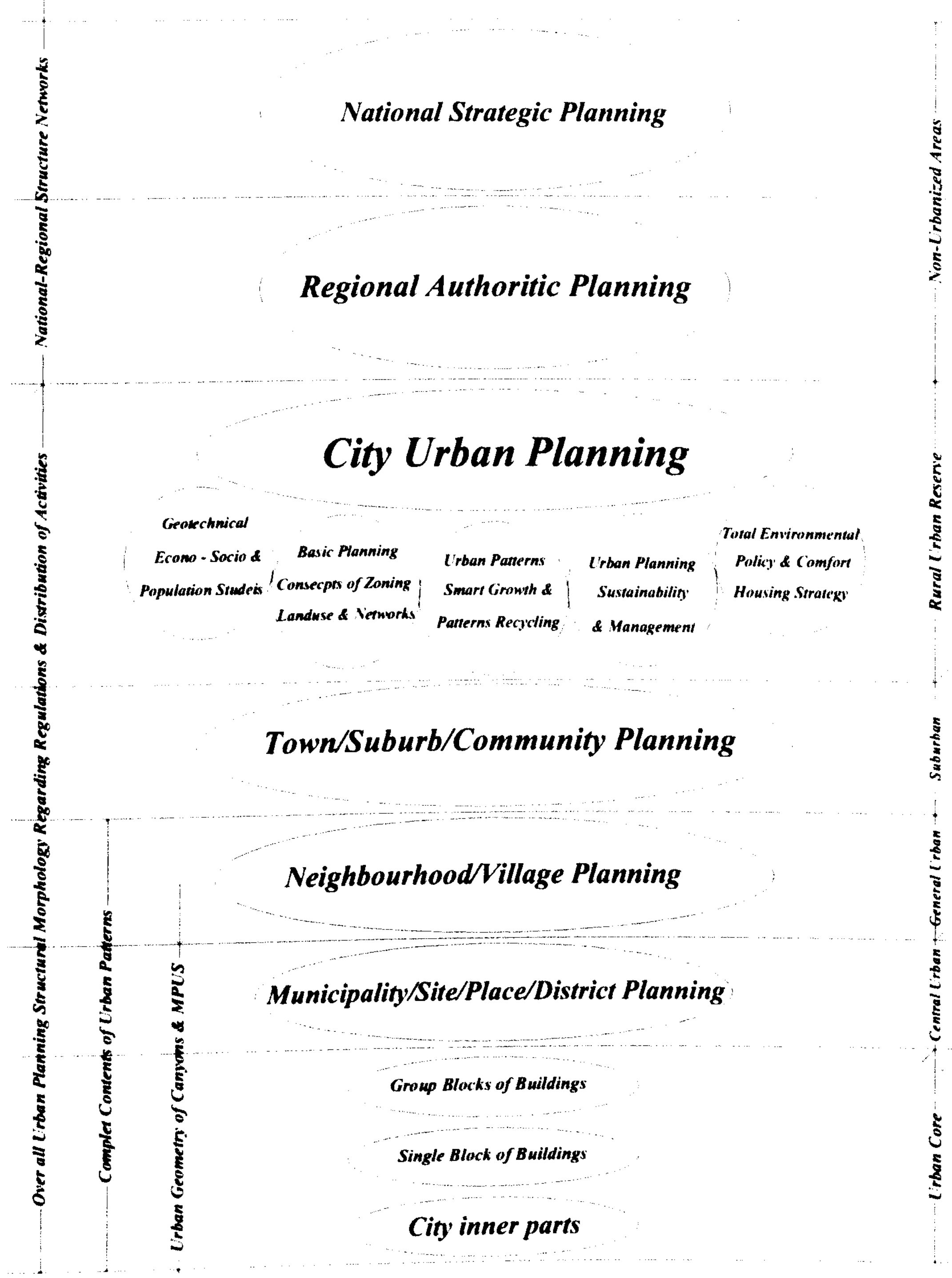


Figure (3-8): Relation between urban planning levels.

3-1-3 Spatial design and types of urban patterns

Figure ground: This is a 2-D graphical base for master planning urban pattern as a black-white or solid-void pattern by adding, subtracting and modifying the geometrical features of pattern sketching from the beginning of pattern design process to change the sequential structural relation of canyons/spaces/buildings of the urban form (Lynch and Hack 1984; Tranick 1986), fig (3-9).

Figure (3-9): 2-D graphical basis for the theory of urban spatial design in plan formality, an edited pattern in Cairo using Photoshop7.0 filters to show the black-white relation of the fabric and its voids, edited by Phtoshop7.0 adapted from Google maps.

Axial linkage: It connects the urban community parts by sketching the vehicle and pedestrian networks as axial lines city needs of zoning and land uses in order to illustrate the circulation system of the urban pattern (Cullen 1961; Tranick 1986), fig (3-10).

Figure (3-10): Hierarchy pattern of the Hausmannian Paris depending on the linkage spatial theory, adapted from Google maps.

Place making: This method of spatial structure design is gathering the previous two methods as it goes beyond them to achieve and utilize; (1) human needs, (2) the historical/cultural/natural features in urban space design. The unique difference appears when the design decision and operations are made to the existing or heritage spaces where a maximum value revealed from the three methods is evolving to preserve, conserve, rehabilitate and restore the urban fabric value (Bentley et al. 1985; Tranick 1986; Bentley 1999), fig (3-11).

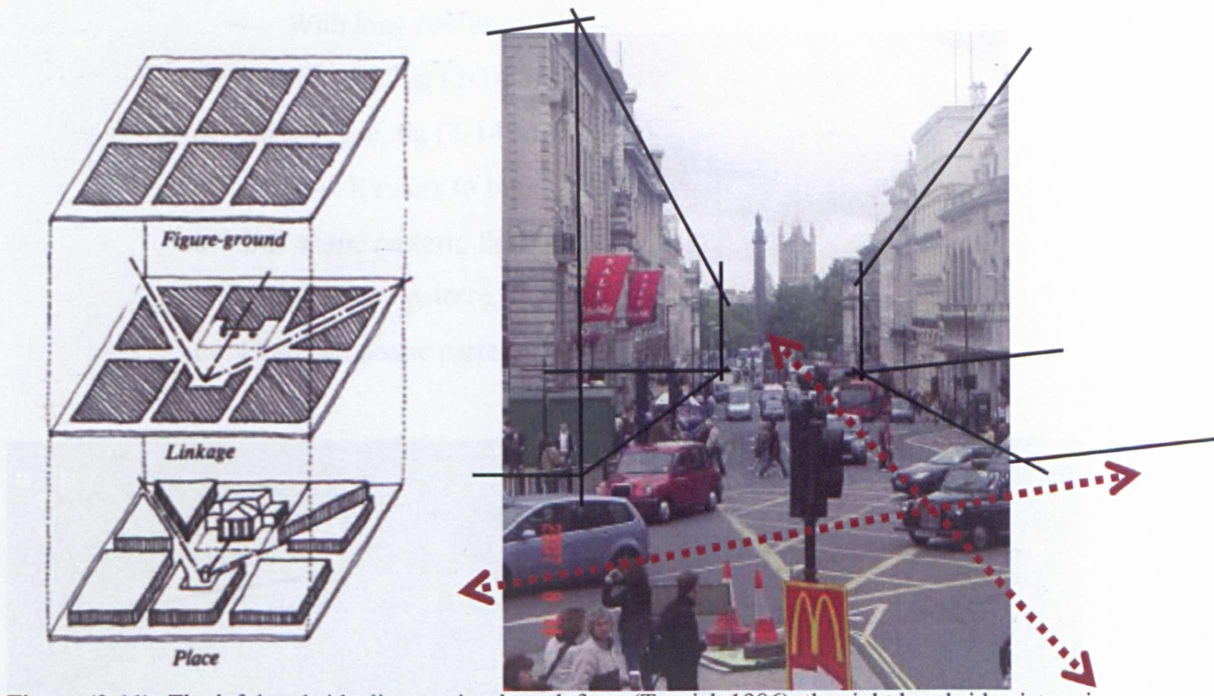


Figure (3-11): The left hand side diagram is adapted from (Tranick 1986), the right hand side picture is captured for Trafalgar square from the Piccadilly circus illustrates figure ground method in terms of buildings as framed in lack lines, axial linkage method in terms of open vision as shown in red axes and place making in terms of the activity at Piccadilly circus at which the picture was taken.

In parallel with the spatial structuring discussed above, urban pattern comes to a stage at which it appears in terms of fabric and network. The expression urban pattern is used to define the final form of urban planning tissues where the lines and intersections of that tissue form the networks, circuses, squares, places, canyons and the buildings (Soliman 2002; Fahmy 2007).

In order to establish an understanding of the basis that an urban passive form designer begin with, an illustrative ***Google map pictures*** *are presented to help classifying different patterns' types which in turn reveal either dot, linear or compact fabric if classified with reference to the fabric aerial view and another different types if classified with reference to the vehicle network shape:*

1- Pattern network types:

a- Grid type, fig (3-12/a, b).

- Normal grid.
- Branched grid.

b- Hierarchy type which can be, fig (3-13/a, b, c):

- Diagonal.
- Radial.
- With long routes.

c- Organic type, fig (3-14/a).

d- Mixed type, fig (3-14/b).

2- Shape of fabric: it refers to buildings;

a- Dot shape pattern, fig (3-15/a).

b- Linear shape pattern, fig (3-15/b).

c- Compact shape pattern, fig (3-15/c).

Figure (3-12/a): Normal and branched grid pattern shape at Nasser City, Cairo, Egypt. This graph and all pattern graphs were adapted from Google maps.

Figure (3-12/b): Normal grid pattern, Riyadh, Saudi Arabia.

Figure (3-13/a1): Hierarchy diagonal pattern, city centre, Cairo, Egypt.

Figure (3-13/a2): Hierarchy diagonal pattern, Tunis the capital, Tunisia.

Figure (3-13/b): Hierarchy radial pattern, Misr Al-gadida, Cairo, Egypt.

Figure (3-13/c): Hierarchy with long route pattern, Heritage Cairo, Egypt.

Figure (3-14/a): Organic pattern, Rade burn, Fair Lawn, New Jersey, USA, www.googlemaps.com

Figure (3-14/b): Mixed pattern, Al-Mohandseen, Cairo, Egypt.

Figure (3-15/a): Dot branched grid pattern, Heliopolis, Cairo, Egypt.

Figure (3-15/b): Linear branched grid for multi family housing pattern, Al-Fangary road, Cairo.

Figure (3-15/c): Compact grid with route pattern around Al-Masjid Al-haram, Makkah, Saudi Arabia

3.1.4 Housing typologies and sustainable urban form:

Whatever the planning statistics that dominate the planning theory thoughts and direct it and whether it is population density, land usage or land bearing capacity for specific each zone function, still residential areas occupy the largest area at any scale and consume nearly half the total energy demands (Akbari et al. 2001; Akbari et al. 2006). The differences come from the urban form design, its activation, development and regeneration and the methodologies. Therefore, a housing strategy decides housing typologies, growth rates and the needed developments rates. Such an approach would not be achieved unless pre-planning studies and checks take place to predict which form provides better ambient climate conditions for pedestrian comfort and for indoor energy consumption. From this viewpoint, housing typologies play an important role to help sustainable urban forms. Urban sustainability is a moral commitment not only for our generations but also for the coming generations, in order to ensure communities perform well in the future (Brundtland 1989). Many have argued for the medium population housing typologies in order to help control environmental problems as well as to provide sustainability (Marcus and Sarkissian 1986; Bentley 1999; Heathcott 2005). Such an approach has been applied in post WWII social urban planning where urban failures have been reached within just 30 years in the late 1970s, but it is believed that urban management systems and centralized development policies were responsible for that rather than the medium population urban housing forms itself (Gill 1994; Ladd 2001; Sutton and Fahmi 2001; El Araby 2002; Ali 2003). This is not revisiting the socialist urban planning, rather a search for thermal comfort sustainable forms. Hybrid clustered fabric with medium population housing came closer to comfort better than single family housing of low population can (Fahmy and Sharples 2009b). Sustainable forms can be identified in terms of seven points (Jabareen 2006);

1- Compactness.
2- Sustainable transport, (and also accessibility to facilities).
3- Density.
4- Mixed land uses.
5- Diversity.
6- Passive solar design.
7- Greening.

Overall, it can be argued that most worldwide urban movements were looking to adjust population density in terms of housing typologies that conclude a specific population to ensure and stabilize people's life style. At the same time construction density can control a single building dimensions, the compactness degree can control a whole site urban morphology (Fahmy and Sharples 2009a). Construction density can be calculated as follows:

$$d = (n \times a_g) / a_p \qquad \text{Eq. 11}$$

Where; d is the construction density, (unit less).

n is the no. of building floors.

a_g is the ground floor area, (m^{-2}).

a_p is the total plot area, (m^{-2}).

Basically, same values of these parameters can generate different types of urban housing form which mean diversity can be obtained at the same time. However, housing types can be classified due to the following criteria (Law3 1982; Marcus and Sarkissian 1986; Law106 1999; Fahmy 2001; Soliman 2002), fig (3-16, 17) show some examples:

1- Due to the number of families in the residential building;
   a) Single family housing.
   b) Multi story apartment housing for single, double or triple floor flats.
   c) High rise housing for single, double or triple floor flats, mostly in city centre neighbourhoods.

2- Due to the fabric form of the residential building;

   a) Detached housing.
   b) Semi-attached housing.
   c) Attached housing with plot construction density from low to medium about 30-70% of plot area, i.e. linear fabric, as in Letchworth and Hampstead, the first garden city examples.
   d) Semi attached or attached housing with high plot construction density above 70% of plot area, i.e. compact fabric.

3- Due to social standards for area and finishing;

   a) Family housing.
   b) Singles housing.

4- Due to economical standards for area and finishing despite its fabric form;

   a) Luxury class residential unit's area more than $200m^2$.
   b) Upper medium class unit's area $120-200m^2$.
   c) Medium class unit's area $90-120m^2$.
   d) Commercial class unit's area $60-90m^2$.

5- Due to the method of financing the building construction and affordability;

   a) Public or private housing investments that are offered for specific groups of people who are capable of buying in cash or instalments within a small period of time despite the residential fabric type or unit classification.
   b) Direct governmental or public private co-operative estate financing that is refunded in a long period of times could be some 20-25 years to increase residential unit's affordability.
   c) Rental housing.

6- Due to urban morphological zone;

   a) Using the new urbanism Transect planning tool (Duany 2002); from urban core towards rural.
   b) Using the degree of compactness adaptor of (Fahmy and Sharples 2009a); from very compact of a specific population and construction density at cities hearts towards very open at urban rural.

c) Using urban zones of (Oke 2006); UCZ1 of specific roughness and aspect ratio at central urban towards UCZ7 at urban rural.

Figure (3-16/a, b): Detached and Semi-attached family housing in Madinaty, east to the Fifth Community, New Cairo, Egypt, adapted from; http://www.madinaty.com/Villas.aspx

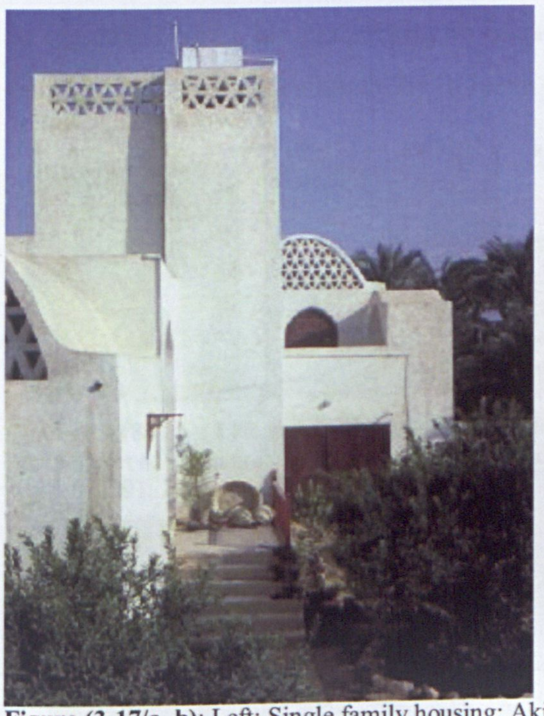


Figure (3-17/a, b): Left; Single family housing; Akil Sami House, Dahshur, Egypt, Right; multi story apartment housing; Jabria Housing, Kuwait city. Both picture adapted from (ArchNet 2010).

3.2 Learning from precedents:

3.2.1 Arabic vernacular derivatives of passive urban cooling:

The contradiction between the western urban architecture and the vernacular urban architecture and housing typologies of the Middle East, Egypt and Cairo discussed in section 3.1 can be realized from figures (3-19) through (3-23). Early concepts of urban compactness can be attributed to the Arabic Saharan urban architecture with its famous elements of narrow streets and courtyards. Confined urban spaces in Santa Cruz, Spain has been studied by (Coronel and Alvarez 2001) and found that the narrow street canyons (H/W = 5) are very important in the thermal behaviour in the summer. Because of the reduced solar access, use of white colours, and the weak anthropogenic heat generation; air temperature decrease of 8°C was recorded in summer. Almost the same findings were achieved by (Johansson 2006) in Fez, Morocco. Reduced wind speeds and the thick walls used reduced nocturnal cooling. Such thermal effects were mainly introduced in the major Arabic cities before it transferred through Muslim Spain in the medieval ages (Shafaey 1982; Jayyusi and Marín 1994; Aben 2001), and is having concern at present as an urban form adaptation solution for climate change (McEvoy 2007; Wilby 2007).

The other main element of Arabic vernacular architecture is the court that is used to regulate climate for the looking-in house spaces in hot climates rather than looking-out that increases the vulnerability to harsh conditions, figures (3-18) through (3-23).

Figure (3-18/a, b): Left graphs in Santa Cruz district in Seville, two in the right Fez in Morocco; the Arabic joint of urban architecture transferred to Andalusia vie Morocco, adapted from (Coronel and Alvarez 2001; Johansson 2006).

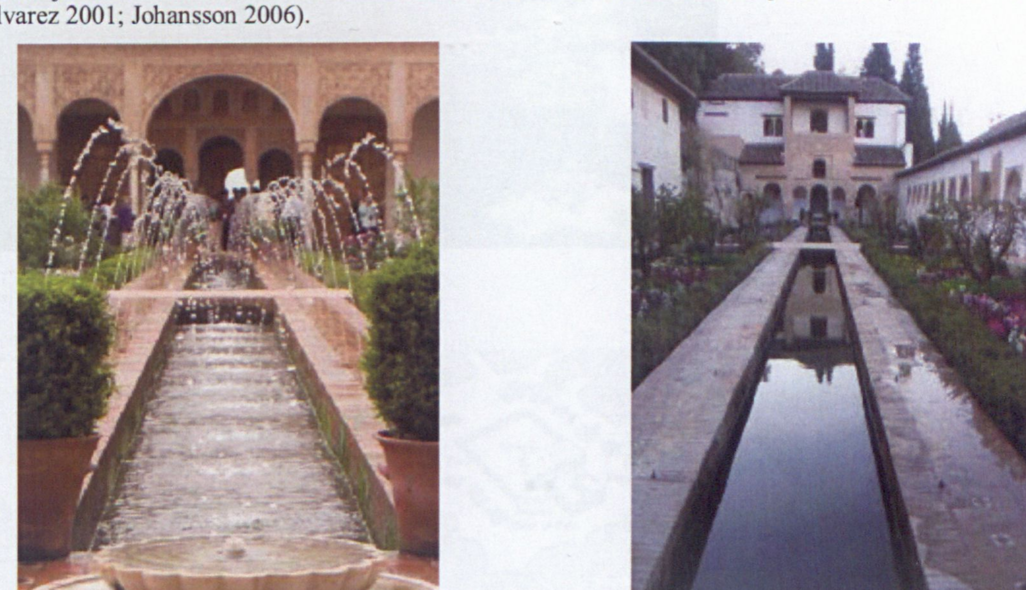


Figure (3-19/a, b): Left; Alhambra Palace Gardens, Right; Al-Aref Gardens, both in Ghernata, the Arabic name of Granada in Spain (Jayyusi and Marín 1994).

Figure (3-20/a): Courtyard of Wekala of Sultan Al-Ghury (Trade mall), at Al-Azhar District of the Fatimid Cairo (ArchNet 2010).

Figure (3-20/b): Ceiled streets in the Fatimid Cairo, adapted from Google pictures.

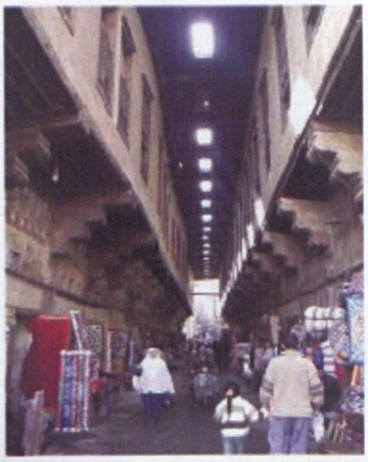


Figure (3-20/c): Interior courtyard of Alsuhaimy House in the Fatimid Cairo (ArchNet 2010).

Figure (3-21/a): The story of Arabic urban planning can be abbreviated from the historical development of ancient compacted cities, above is AL-kufa city, Iraq, (Al-saiad 1996).

Figure (3-21/b): Historical development of ancient Cairo from the initial plan by the Commander Goher on the right to the final form at the end of the Fatimid era on the left, (Shafaey 1982; Said 1988; Fahmy 2003).

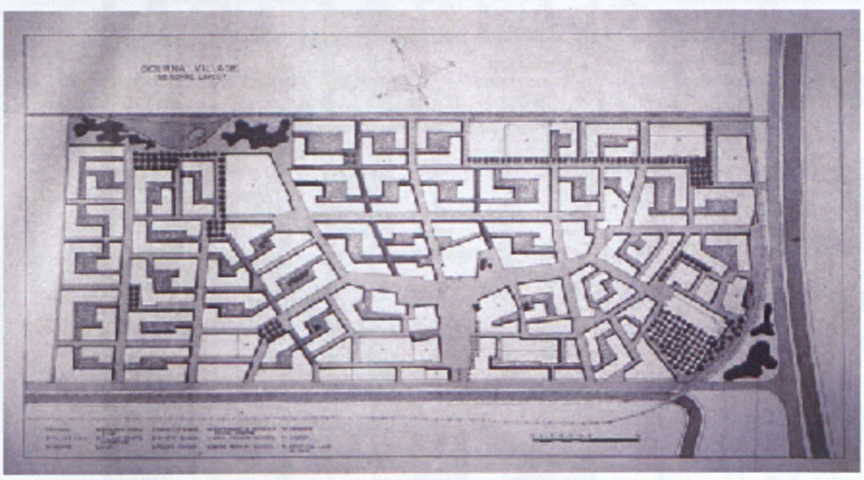


Figure (3-22): Mass plan of new Gourna Village of upper Egypt, 20th century urban vernacular architecture by Hassan Fathy designs, following the Upper Egypt compact vernacularties of lower latitudes (Fathy 1973).

Although there is no universal solution for climatic urban planning (Oke 1988), for hot, dry climates the traditional courtyard and cluster are perceived as a successful form due to its universal innovative climatic response (Fathy 1973; Fathy 1986), it is an intelligent urban form (Swaid 1992) and bioclimatic housing suitable in different climatic regions as solar protector as well as collector despite its usage in a cold weathers didn't almost have a climatic control or privacy provision reasons as in the hot Arab region (Edwards 2005; Raydan et al. 2005). Urban streets and courtyards with trees achieved cooling effects of around 4.5°C by the CTTC model (Shashua-Bar and Hoffman 2004). Orientating courtyard axis in Fatimid Cairo by 60° from North was the optimum for summer cooling and winter heating whilst an orientation of 75° to 90° from North was optimum for the low latitude location of Toshky in Egypt (latitude 22° 45'N), (Waziry 2002). This second finding is in good agreement with (Bourbia and Awbi 2004), who concluded that *"under low latitude conditions deviation of the street from E-W orientation may often be a desirable criterion in urban design"*, p-300.

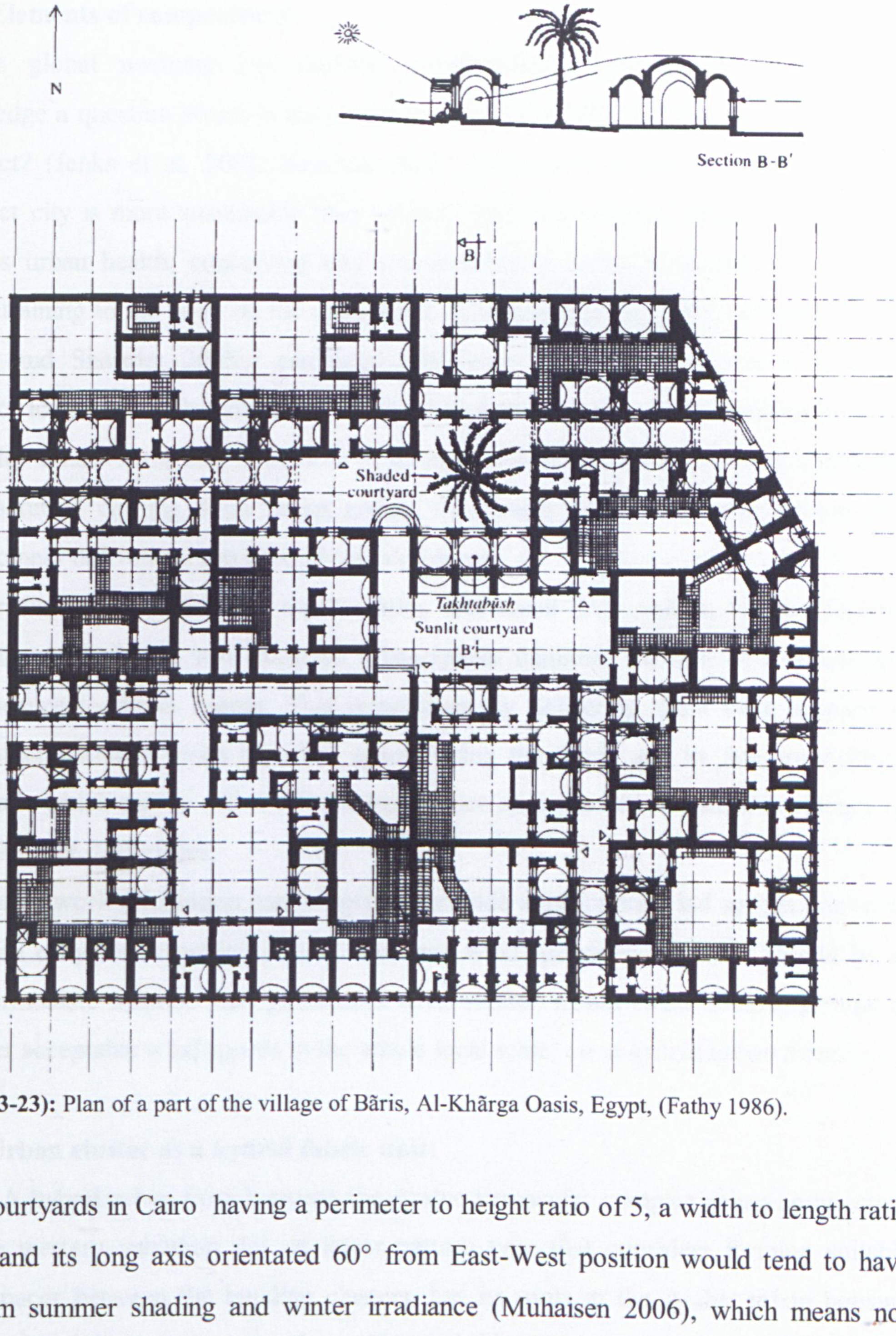


Figure (3-23): Plan of a part of the village of Bãris, Al-Khãrga Oasis, Egypt, (Fathy 1986).

Courtyards in Cairo having a perimeter to height ratio of 5, a width to length ratio of 0.5 and its long axis orientated 60° from East-West position would tend to have optimum summer shading and winter irradiance (Muhaisen 2006), which means not only the orientation is critical but also the courtyard closure ratio. Courtyard closure ratio, C_a also investigated by (Waziry 2004) and defined as;

$$C_a = A_w / A_g \qquad \text{Eq. 12}$$

Where A_w is the area of the courtyard interior walls and A_g is the area of the courtyard ground floor, and both in m^2.

3.2.2 Elements of compactness:

As global warming has become an established platform in urban climate knowledge a question arose: is the compact form sustainable and is it sustainable to get compact? (Jenks et al. 2002; Neuman 2005; Atkinson-Palombo 2010) reported that compact city is more sustainable than sprawl. In terms of other sustainability factors such as urban health, conceiving city sustainability in terms of its whole process is more attaining to the goal; on the other hand (Ali-Toudert et al. 2005; Johansson 2006; Fahmy and Sharples 2008c) presented that better comfort levels can recorded in compact forms but with reduced wind access as a penalty. From this standing point, to argue for a new form that is capable of giving comfort as well as allowing ventilation and nocturnal cooling from urban nodes, the Arabic vernacular urban architecture compactness derivatives can be analyzed as follows:

1- Narrow spaces with high aspect ratios and small SVF values, where clustered courtyard buildings with confined urban spaces minimize the time of a pedestrian's exposure to direct access. This is achieved by delivering them from a space to another within a series of urban spaces using the fabric and its fine architectural details which can be called urban consequence spaces owed to their dependency on each other, UCSpaces.
2- Fine network orientation can sometimes provide appropriate wind speeds due to an urban canyon's tunnelling effect. Reduced wind speeds means there should be an intermediate solution that guarantees solar shelter within small housing groups to offer acceptable wind speeds in the whole local scale, *i.e. a hybrid urban form.*

3-2-3 Urban cluster as a hybrid fabric unit:

A hybrid urban form between the Arabic vernacular compact urban architecture and the western suburban dot or linear pattern type that considers forming suitable green spaces between the building clusters, has its roots in the Arabic urban housing designs well known as courtyards or Housh in Arabic language. an arid cluster is considered a sensitive design element by (Rahamimoff 1984), it can be considered an intelligent urban form (Swaid 1992). Colonnaded street canyons and fabric detailing in terms of special designs to improve climate conditions is argued by (Ali-Toudert and Mayer 2007b), whereas (Aldawoud and Clark 2008) found that courtyards are better in performance than atriums for short buildings if limited in courtyard façade glazing ratio up to 6 floors on average. (Fahmy and Sharples 2009a) examined orienting canyons with 75° orientation from north for the best comfort performance, irradiation minimization and shading maximization. (Ahmad 1994) investigated the closure ratio for courtyards in Cairo at 30°N and found that a closure ratio of 3.45 (courtyard walls' areas divided courtyard ground area) with W/H/L of 1:1.3:3 is optimum at 15° from E-W axes for the main courtyard axe which is 75° from N-S axes. This form can effectively respond to the excessive conditions of hot-dry climates, (Golany, 1996) have discussed the urban forms in relation to the climate region as a review without a for ground design suggestions except the Earth-sheltered construction which is a single housing unit rather than a complete pattern.

As a conclusion, a proposed hybrid urban clustered form can be characterised by the following:

1- To arrange housing units around a large courtyard for passive cooling, not single building or house but is a group of buildings, so;
2- It is Attached/semi-attached housing which is the most used type of buildings to form the settlement.
3- Medium population density with ground floor plus 3-5 floors could be assessed with reference to the aspect ratio H/W for streets and W/L/H for cluster courtyards.
4- Assumed to be used in the zones of central urban, general urban and rural urban by controlling the aspect ratios H/W for streets and W/L/H for cluster courtyards to have particular construction densities in each urban zone, i.e. from D2-D4 on the degree of compactness scale.

3.3 On the development of an urban passive form

This section presents the pilot study of (Fahmy and Sharples 2009a) where the a theoretical quarter neighbourhood is simulated to investigate how urban patterns can be designed to act as a passive cooling system with respect to the clustered urban form on a neighbourhood basis concluded from both sections 3.1 and 3.2 as a hybrid form. This microclimate study is a preliminary investigation prior to the application of the proposed urban passive form on a local scale which in turn can be considered a proposed climate based improvement for the traditional neighbourhood form. An urban passive system can utilize two main elements, the urban fabric form, with its green structure, and thermal comfort adaptation by introducing urban green scene stimulation with the time of exposure to the urban environment regardless adaptation thermal impacts can not be assessed directly by the software except for the shading produced in terms of short-wave direct radiation interception, fig (3-24).

Stimulation by green scene has followed conclusion of the 90 papers review article done by (Matsuoka and Kaplan 2008) for the people needs in their urban landscape. This study reports that contact with nature, its quality, elements and views *"contributes to improved quality of life, even if the encounter is only a brief opportunity to escape the urban bustle, relax, and possibly contemplate or enjoy the time in nature."* p-9. This completes the meaning reported by (Nikolopoulou and Steemers 2003) who said that "*Environmental stimulation is an issue of primary importance in external spaces, where the environment presents few thermal constraints, this being an important asset of such areas and one of the reasons that people use these spaces. Environmental stimulation is probably the main reason for the majority of people to sit outdoors*", p-98.

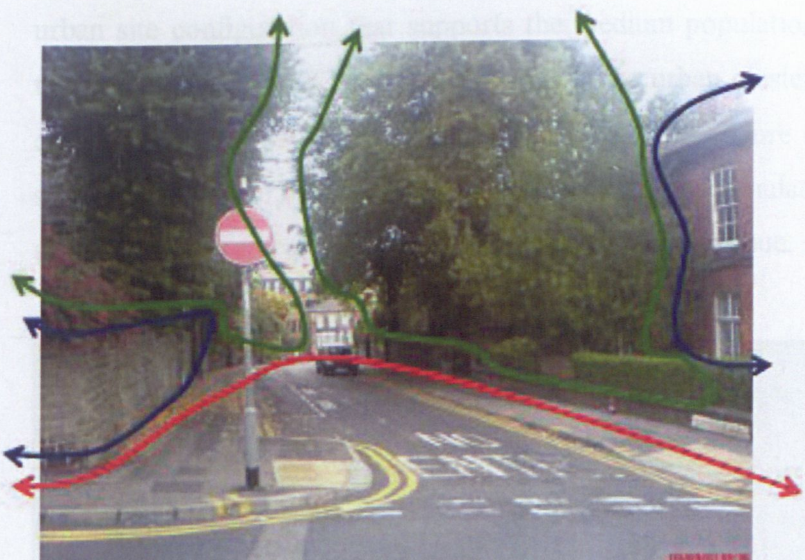


Figure (3-24): Urban green scene: (1) the lower part by the red dotted line is the canyon flooring, (2) facades as middle part of urban scene, (3) green line defines green colour of urban trees canopies, upper part of the scene or the canyon's ceiling, Broomhall, Sheffield, UK. Published in (Fahmy and Sharples 2009a).

3.3.1 Site planning, fabric and housing design:

In addition to the clustered form, the idea of parallel shaded un-shaded avenue is suggested as a passive spatial structure. Therefore, urban canyons in a grid network were examined, with one canyon having virtually no shade and other canyons had a green structure containing two types of native Egyptian trees to investigate cooling effects from the green ones towards the non-green irradiated ones. The concept is to generate an overall cooling effect if possible at immediate surroundings of the avenue parallel shaded un-shaded canyons by pressure difference as well as allowing wind tunnelling effect to increase cooling possibilities. Fabric is designed to cope with the Egyptian urban planning law (Law3 1982) that tells a population of 100-150/faddan (faddan is an Egyptian area measuring unit = 4200 m^2) of medium housing, table (3-1).

Two sets have been designed to stand for different compactness degrees upon different population. Housing type used is the attached linear fabric multifamily apartment buildings having module of 150 m^2 of total flat area which suits a family of 4-5 persons and can be divided or gathered with more adjacent to decrease or increase the unit area.

Figure (3-25) indicates a 3-D graphs for urban form design sets, table (3-1) illustrates urban site configuration that supports the medium population and fabric to cope with the population limit of Law (Law3 1982). The urban cluster proportions for the four compactness degrees are shown also in table (3-1). Figure (3-26) illustrate the green structure and (3-27) show points placed for recording simulation output across the two shaded avenues and along the main middle un-shaded avenue.

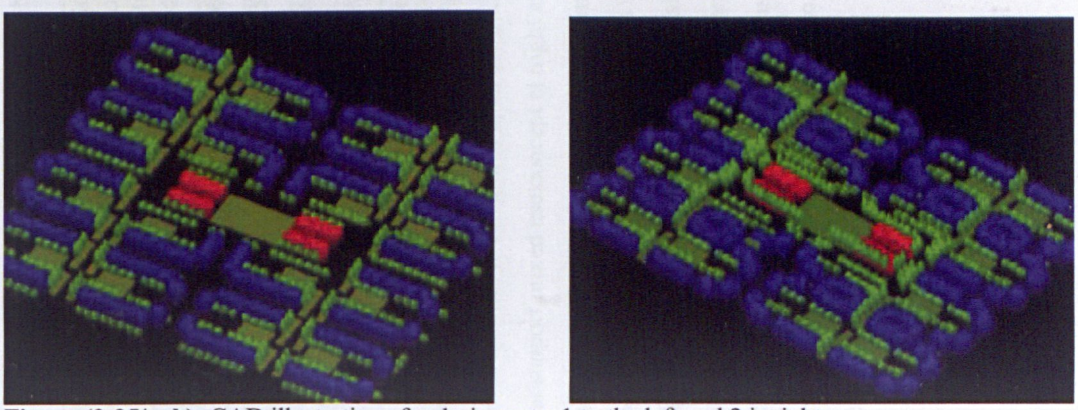


Figure (3-25/a, b): CAD illustrations for design sets; 1 to the left and 2 is right.

Table (3-1): Housing and land use statistics of the empirical passive spatial form;

	Name	Urban area in feddans	A_g (%)	Cluster closure ratio;	Cluster aspect ratio; H/W/L	A_c (%)	n_f	D_c	Max. No. of families	Population	Population /feddans	Law no.3
1	Set1_Dc1	51.07	0.251	0.494	13/50/200	21.8	3.875	0.844	1120	4200	82.24	100 - 150 person/ feddans
2	Set1_Dc2	51.07		0.608	16/50/200	21.8	4.750	1.036	1408	5280	103.38	
3	Set2_Dc1	37.24	0.183	0.515	13/42/180	26.5	3.923	1.040	1144	4290	115.20	
4	Set2_Dc2	37.24		0.635	16/42/180	26.5	4.923	1.302	1236	4635	124.46	
5	Set2_Dc3	37.24		0.635	16/42/180	28.0	5.846	1.549	1424	5340	143.39	

- D_c is the compactness degree standing for fabric volume, i.e. residential construction percentage $A_c \times$ canopy layer height, or the number of urban floors n_f which in turn can be calculated from the population. A_c is the urban site constructed area percentage. A_g is the green coverage area percentage (%).
- No. of families is calculated upon subtracting ground floor dwellings of the main middle avenue from residential use to be as commercial and recreational uses that support mixed use concept at night after losing heat by nocturnal cooling. Family no. of flats is also calculated as 150 m^2/flat/family.
- Facilities buildings at service civic centre are 10 m in all design sets and 13 m in Set2_Dc2 to increase the compactness degree without increasing site population assuming that more facilities are needed.
- The actual residential land use can be calculated after extracting 33% for the network and green coverage as (Law3 1982) tells, also after extracting the civic buildings areas, hence the residential land use for example for Set2_Dc3 is 23.707 feddans is 63.66% of site area, i.e. the actual constructed area which is 10.428 feddans gives construction percentage of 43.99 %.
- Refer to eq. no. 1 for cluster closure ratio.
- Feddan = 4200 m^2

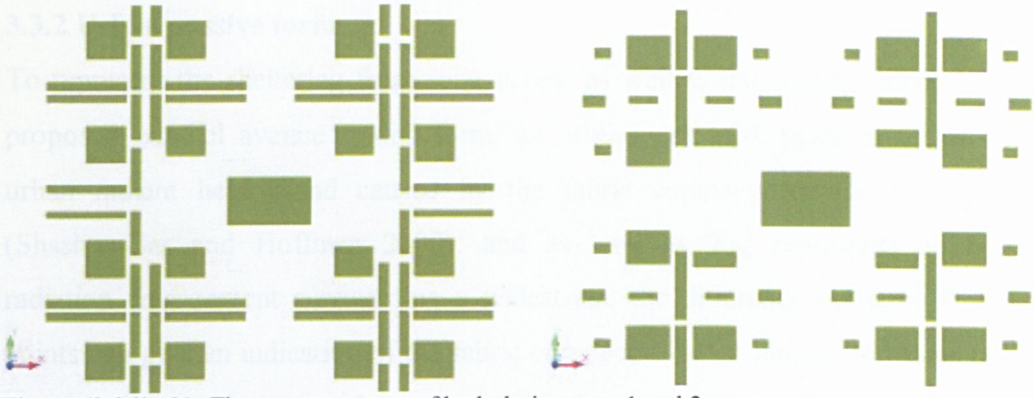


Figure (3-26/a, b): The green structure of both designs sets 1 and 2.

Figure (3-27/a, b): Snapshot receptor positions for design sets; 1 is top and 2 is below.

3.3.2 Urban passive form

To represent the sheltering from solar access as well as the cooling effect due to the proposed parallel avenue spatial form, an assessment took place in terms of local urban radiant heat island caused by the fabric compactness, LUHI. Following (Shashua-Bar and Hoffman 2000), and as long as T_{mrt} represents all net-wave radiation environment surrounding a pedestrian, the difference between T_{mrt} of two points can give an indication of the fabric compactness that intercepted solar radiation at one of them if compared to a second reference point provided that it is almost exposed all day to radiation. That is why the middle canyon, at which the reference point no.1 is located, doesn't have trees to allow solar exposure, whereas the smaller aspect ratio compared with the vegetated avenue canyons is to allow more sensible heat emissions from walls near the point no.1. Point no.1 is considered the reference point for the two points at the civic garden (no.9) and at the green shaded point in the pedestrian green avenue canyon at (no.4).

However, LUHI is then calculated as the difference between T_{mrt} at the reference point in the un-shaded avenue and two other points at the civic centre and in the shaded avenue, fig (3-28), in another word results are presented as LUHI of (point no.4-point no.1) and LUHI of (point no.9-point no.1).

Orientations were 15°, 45°, 75° each of them had different compactness degrees (as defined in Eq.8) were simulated. Applying numerical CFD simulations for hot climate conditions, and despite some very hot conditions were recorded, there were evident examples of more alleviated conditions and cooling potential for some orientations and degrees of urban compactness due to the clustered form with green cool islands and the tunnelling effect through the main canyons. The (-) LUHI value means that T_{mrt} far from the irradiated reference point is less and hence a cooling potential is recognized. Comparisons of LUHI in all cases show that the preference is for the orientations at 15° and 75° degrees as they display steady differences and (-) values more than of 45° which means more cooling effect or in fact less heating effect. This proves the applicability of the parallel avenues clustered form to act climatically well, if Dc is to be adjusted considering local land use and housing needs but with caution to thresholds of population.

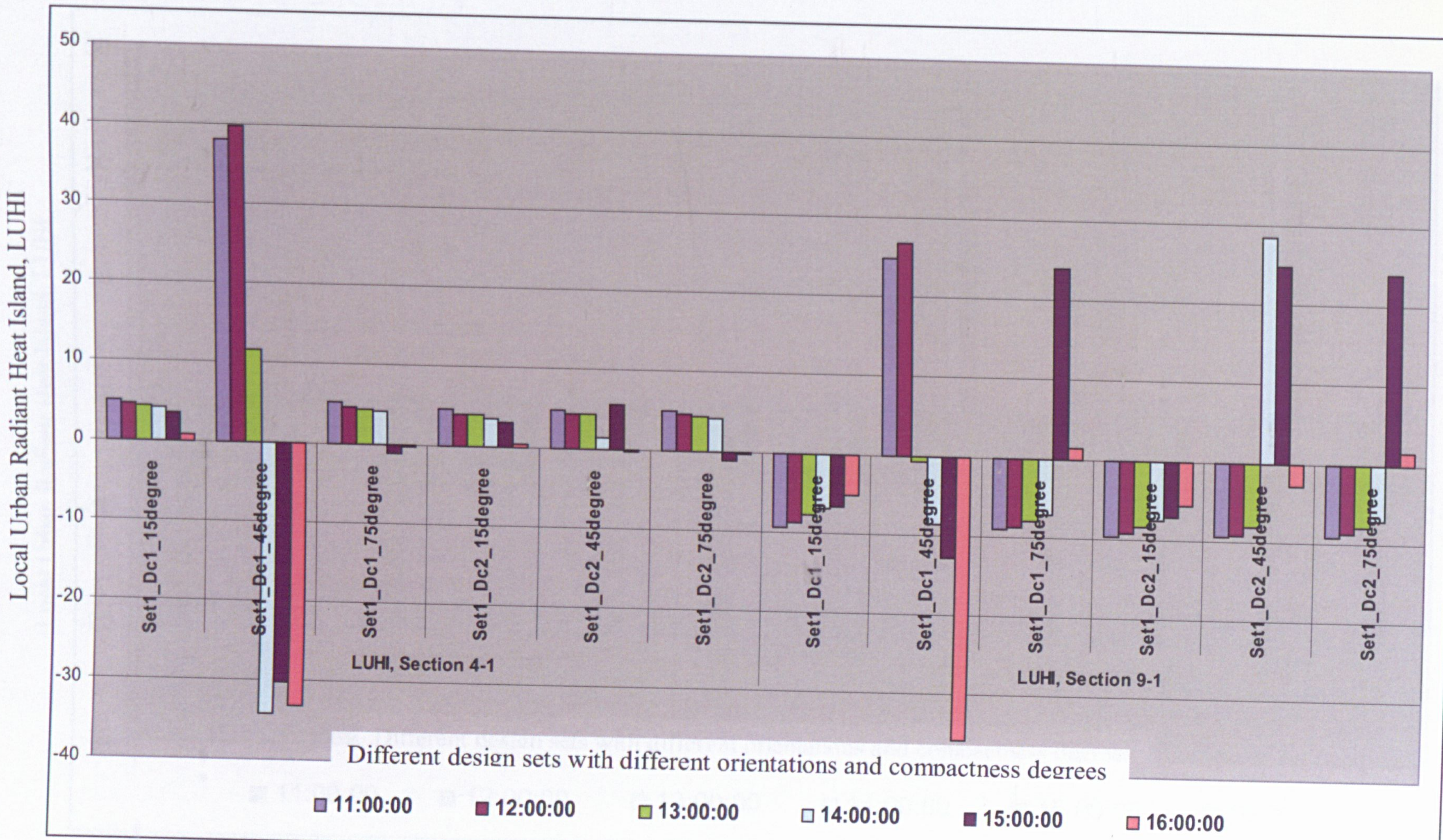


Figure (3-28/a): LUHI of Set1 Dc and orientations. The y-axes represent a unit less value of the Local Urban Radiant Heat Island, LUHI.

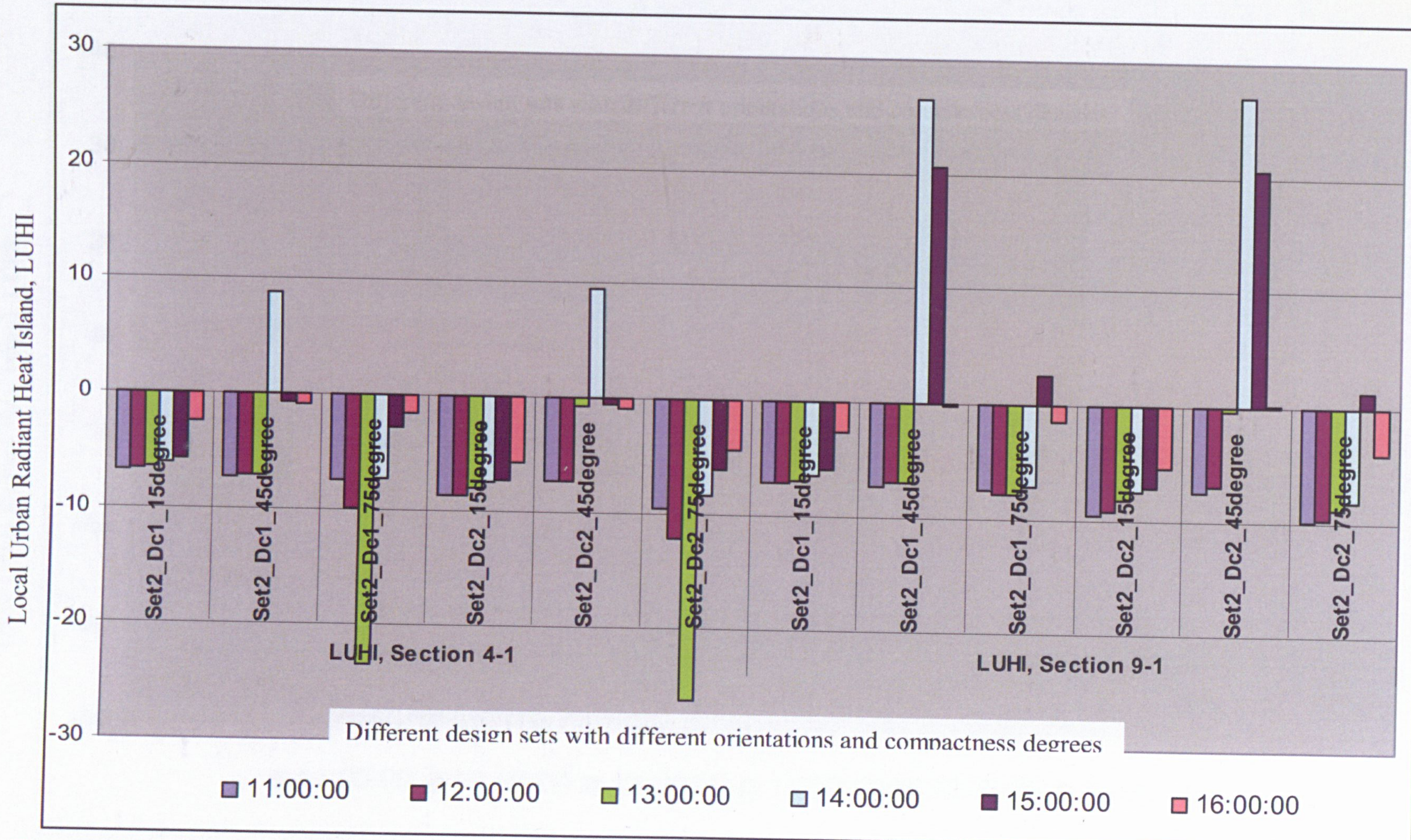


Figure (3-28/b): LUHI of Set2 Dc and orientations. The y-axes represent a unit less value of the Local Urban Radiant Heat Island, LUHI.

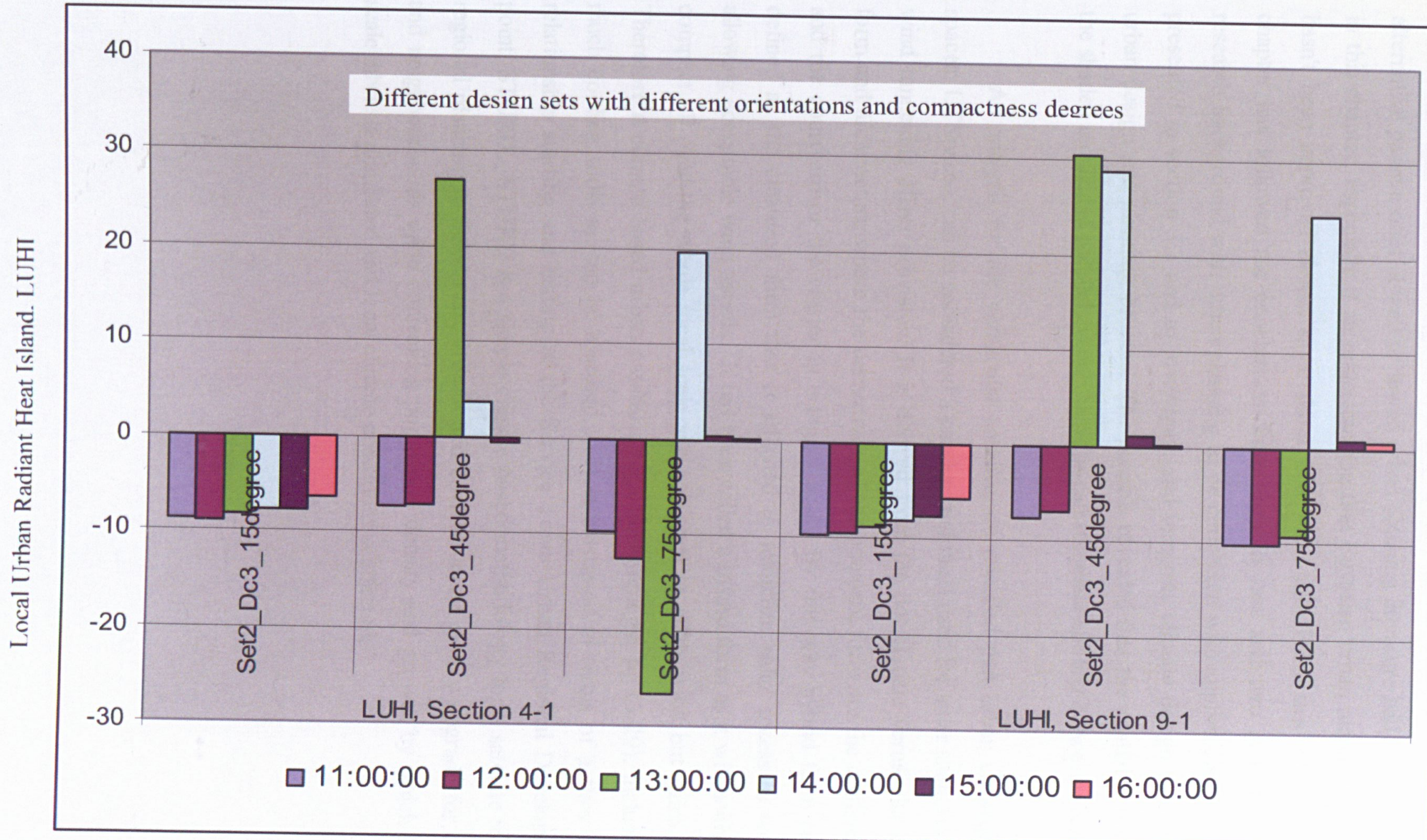


Figure (3-28/c): LUHI of Set2_Dc3 of all orientations. The y-axes represent a unit less value of the Local Urban Radiant Heat Island, LUHI.

3.4 Summary

In order to study the thermal impact of local scale urban forms and to generate alternative passive ones, a well reviewed urban planning literature had to be presented in this chapter, especially if an understanding that Egyptian urban planning discipline hasn't been improved almost since about 100 years ago. From this viewpoint, this chapter has followed the conclusions from chapters one and two in widening the research background with urban planning to be connected with applied climatology as presented in section 3.3 and to investigate and integrate climate design tools within urban design and planning process. The process revealed that the spatial concept of the shaded un-shaded parallel avenue canyons can stimulate cooling between avenues.

An analysis for the vernacular architecture revealed that urban consequence spaces, UCSpaces, can be considered a passive tool itself used for solar sheltering and wind tunnelling effect provision. It is derived from the hot climate vernacular urban form and architecture where the derivatives of the compact form are the confinement and the courtyard or the cluster in a bigger scale. By this way hybrid form can be defined as the clustered form that is adjusted to minimize solar access as well as allowing acceptable wind speeds. It has been called a hybrid form as it will neither be compact all over the whole local scale site nor open to allow wind but gains heat. Therefore a climate based urban passive design methodology; fig (3-29), includes as much cooling tools as can be assessed. It is illustrated in terms of a flow chart relationship starting and ending at the Service Town Urban Regional Development point, STURD. STURD is a simple climate based methodology for a satellite town's regional planning to help smart growth and environmental quality upgrade for cities and neighbourhoods upon controlling population density and growth by which local scale fabric is generated and local climate conditions is affected.

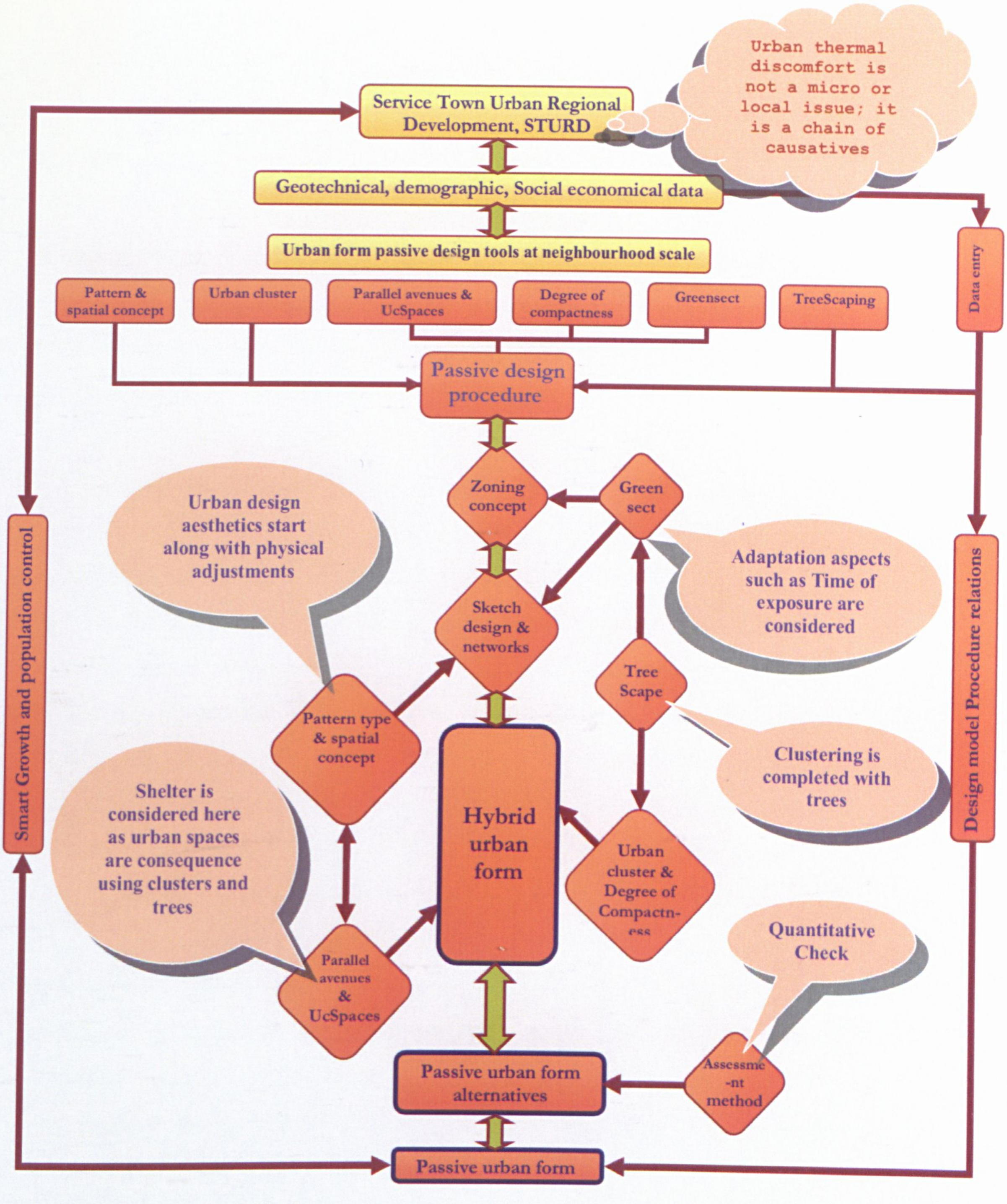


Figure (3-29); Research methodology for urban form passive design. It is defined *from a city side point of view,* rather than from a single traditional neighbourhood development (TND) point of view or even in terms of an urban village except in special cases of separation from the nearest cities.

Chapter four: 100 years of urban growth in Greater Cairo; Introduction to case studies

4-1 Introduction

As the previous chapters presented and discussed urban climate and urban planning literature along with sub-methodological investigations dedicated twards ensuring the methodology of passive spatial design of urban form, this chapter analyses the local scale cases of the main core of this research that work presented in previous chapters will be applied to examine them.

4-1-1 Urban development history of Greater Cairo – "Umo Edonia":

Cairo is located in the multi cultural country of Egypt, which lies between three continents from Lat. 22° - 32°N and Long 25° - 35° E. Cairo, N 30° 7', E 31° 23' GRT +2.0, is the capital of Egypt and its name is an English modification of the Arabic word Al-Qahira, named after the star Al-Qahir. This name had been given to Cairo by the famous Fatimid sultan Al-moez Le-Din Allah, who ordered his army leader Gowher AL-sekelly to do that. He set the city to the north of the ancient city of Al-Fustat and its extension was developed by one of the prophet Mohammad (PBUH) companion's, Amr Ebn-Ala'as, in the 6^{th} century BC, about 64 years in the Hijjry lunar Calendar. That unique location made Cairo the political kitchen, furnace, and pivot of many great events on the Middle East along with its urban planning historical developments what gave Cairo the name "Umo Edunia", i.e. the head, origin or mother of the world in sight of Egyptian people and even the Arabic adjacent countries' people. In fact, its political economies were the motives for all of the development trends. (Stewart 1999; Stewart et al. 2004; Yin et al. 2005) have demonstrated four time periods of urban planning developments based on field surveys and GIS technical work with different issues maps for Cairo supported by satellite imagery. Those four urban political shifts were responses to population growth, fig (4-1/a, b, c) as follows:

1- Islamic (settling; 979 AD – French occupation; 1798 AD), urban key features are Al-Fustat, the Fatimid Cairo, the Citadel...etc.
2- Imperialist (French occupation; 1798 AD – July Revolution; 1952 AD), urban key features are the central Cairo, Al-Zamalek, garden city...etc.

3- Arabic Socialist (July Revolution; 1952 AD – Transitory; 1987 AD), urban key feature is Nasr City.

4- Capitalism (Transitory; 1987 AD – now), urban key features are the satellite developments of the new town rings.

The case studies in this thesis are from the transition urban planning period around Metropolitan Cairo as an example of changing planning policies that were revealed in new communities of different spatial structure compared to central urban and city inner parts. Cairo started to change its master plan from the late 1970s by having satellite towns planned to attract the population that nowadays makes Cairo the 10^{th} largest worldwide mega city. That is why it has been divided into two more governing areas over the existing three to be five governing areas forming greater Cairo. It has a population of more than 16 million people and its rate of expansion over the last 30 years has overwhelmed the master plans developed for the city in the 1970, 1982 and 1992 modifications (Sutton and Fahmi 2001; El Araby 2002). Different types of urban planning have occurred as the city has sprawled eastwards into the desert.

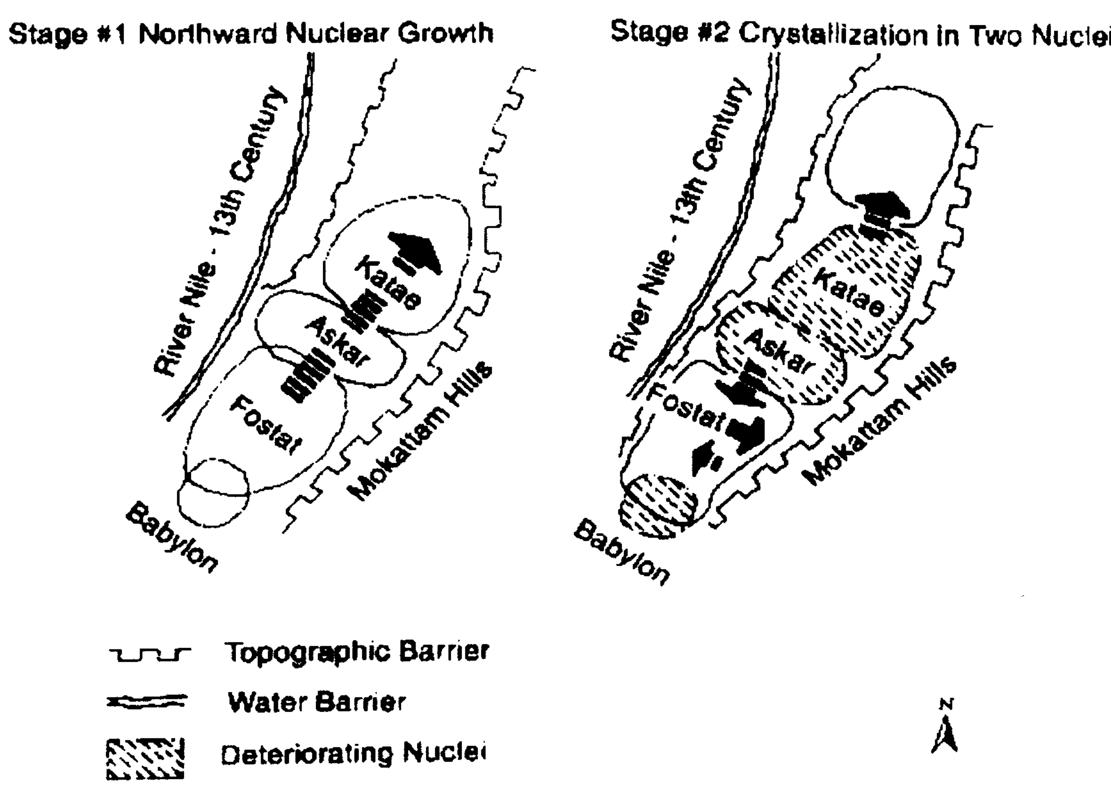


Figure (4-1/a): Cairo development starting from Fustat to the north of the Romans fort Babylon in 641AD, adapted from (Moselhi 1988) and presented by (Yousry and Aboul-Atta 1997).

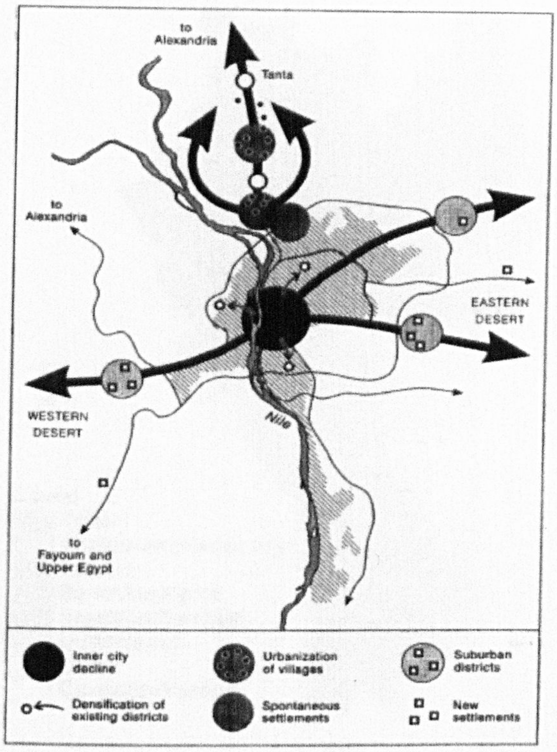


Figure (4-1/b): Model of Greater Cairo's recent and projected development (Sutton and Fahmi 2001).

(Sutton and Fahmi 2001; El Araby 2002; Fahmi and Sutton 2008) give some clarifications towards the recent situation of Greater Cairo's urban fabric, pattern, and master plan from the development and environmental points of view. They claim that the unclear urban and environmental policies to confront and invest in growth along with the lack in parallel urban development that accommodate the population increase revealed urban planning problems which need more than a few years to be solved. The lack of a housing strategy, along with an uncontrolled population density and the absence of the political pressure needed to deeply improve master plans, are the main reasons for the overwhelmed urban patterns. Consequently, urban decline and informal settlements started to appear increasingly in the absence of a strong governmental role (Kipper and Fischer 2009). Egypt's population reached about 79 million at the beginning of 2010 but varied from 76.70 million inhabitants in 2006 to 61.50 million at 1996 with about 43.09% of them living in urban areas in 2006 compared with 42.63% in 1996 (CAPMAS 2008). Cairo Governorate (equal to province or county), the eastern part of greater Cairo, which is the metropolitan Cairo and its extensions, has a population of 6.8 millions spread over about 215 km^2 of urban and rural areas. The Greater Cairo population exceeded 16 million in 2006. Its populated area expanded from about 345 km^2 in 1986 to about 460 km^2 in 1999 (Yin et al. 2005).

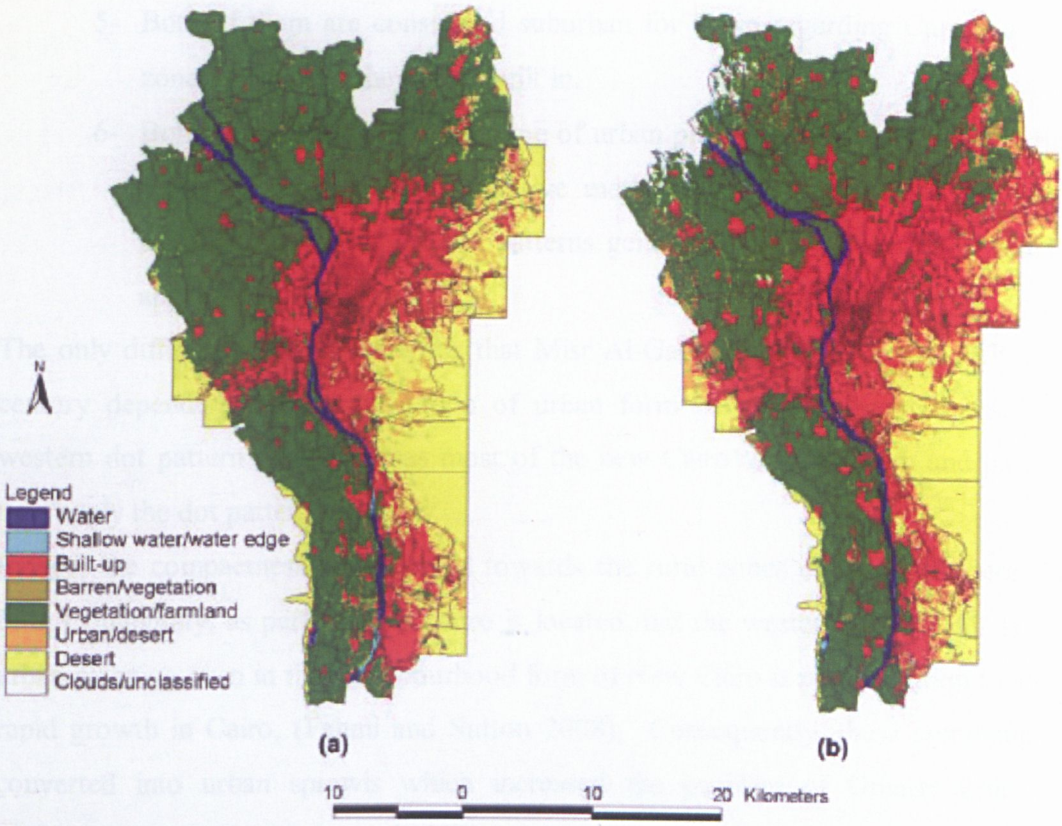


Figure (4-1/c): Greater Cairo urban growth and land use 1986 is left and 1999 is right, adapted from (Yin et al. 2005).

Two neighbourhood areas (the Fifth Community and Misr Al-Gadida) were chosen as cases studies for this thesis in order to make urban form based comparisons between them upon their different thermal performances. The first case can be described as a neighbourhood dot pattern single family villa housing, which is the common feature of New Cairo, the extension of Cairo to the east due to urban development plan of 1982 and its modifications in 1992. This is not only unlike the heritage background of housing and patterns types in historical Cairo, but is unlike the early 20th century urban developments to the North-East. The urban morphology of the second case belongs to the late imperialism planning policy, with Misr Al-Gadida being built early in the 20th century, despite its housing fabric being mixed between small and high rise apartment buildings which were built as an extension to Misr Al-Gadida core in the Arabic socialist planning period. Selection of cases is based on the following terms:

1- They are located in a hot arid region.
2- They are almost on the same latitudes.
3- They have the same cultural, social, urban and architectural features.
4- Both of them were new communities regarding the time they were built in.

5- Both of them are considered suburban for Cairo regarding Cairo's urban zones at the time they were built in.

6- Both of them are a western type of urban planning, this is to examine the proposed urban planning passive methodology on more than one case having different fabric and patterns generated from the same previously applied methodology.

The only difference between them is that Misr Al-Gadida was built in the early 20th century depending on a combination of urban form between compact, linear and western dot pattern type, whereas most of the new Cairo' s urban form and pattern type apply the dot pattern type only.

Indeed, the compactness is decreased towards the rural zones of the city where the Fifth Community, as part of New Cairo is located, but the western type of dot fabric urban planning even in the neighbourhood form of New Cairo is not a solution to such rapid growth in Cairo, (Fahmi and Sutton 2008). Consequently, these communities converted into urban sprawls which increased the problem of Greater Cairo in addition to environmental sustainability problems. An urban planning statistics and tabulated land use comparisons with the proposed climate based neighbourhood planning of this research will be presented in chapter five.

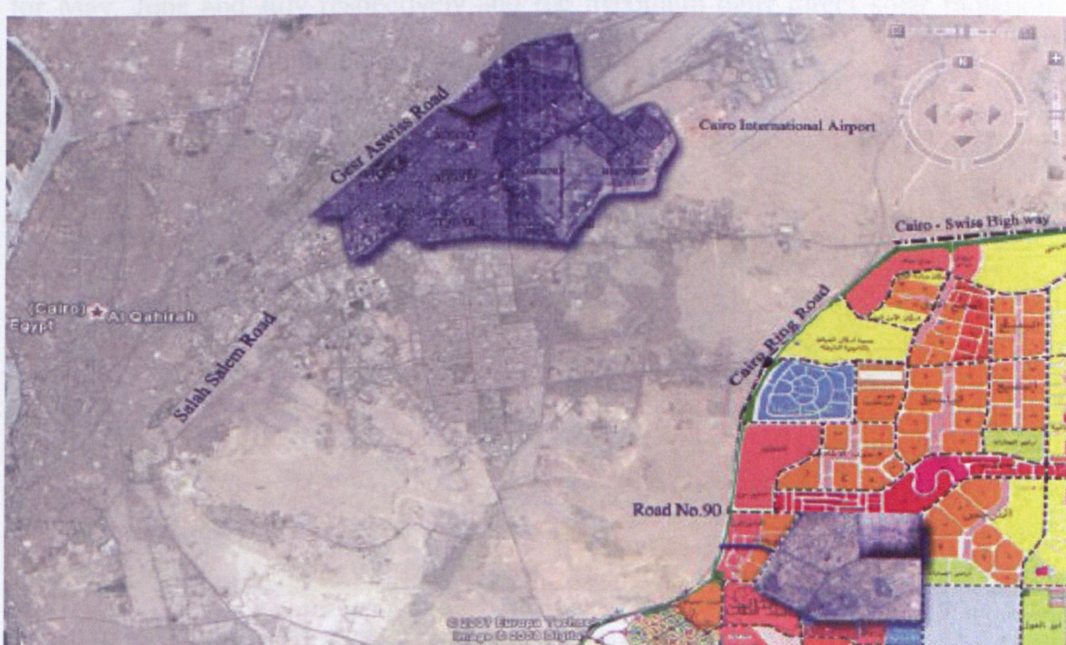


Figure (4-1/d): Location of Research cases, edited from Google maps. Middle left is the metropolitan Cairo started with Al-Fustat, to the north and west Nile are the imperialist extensions. Highlighted with blue is southerly began in the imperialist but extended after the 1952 revolution. Far southeast is new Cairo outside greater Cairo's ring road. Graph is an edited Google maps capture by Photoshop7.0.

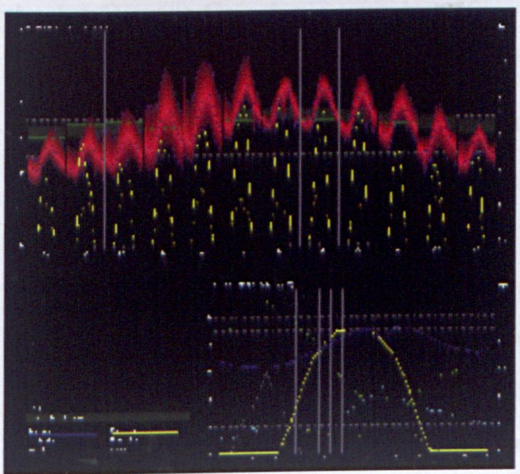
In order to support both cases' numerical modelling and thermal performance simulations and analysis Quick Bird satellite imagery of 0.6 resolution and digital maps in Shape files format were processed using ArcGIS 9.2 software to import physical dimensions of both cases and to support design decision. Table (4-1) illustrates the coordinates of the two case studies.

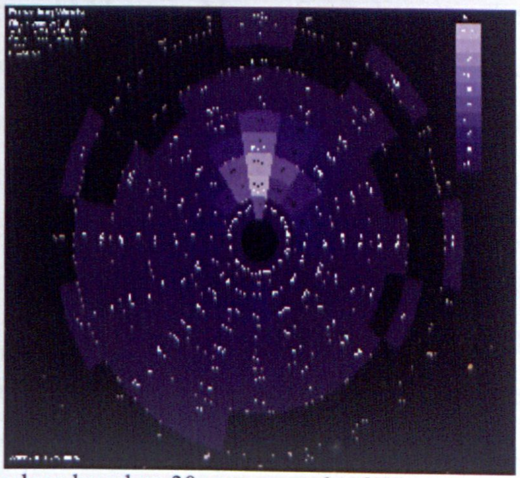
Table (4-1): Coordinates needed to provide GIS data of the geometry of the cases.

Long. & Lat.	1st corner point	2nd corner point	3rd corner point	4th corner point
Misr Al-Gadida	30°7'17.76"N 31°20'28.32"E	30° 6'20.43"N 31°19'14.44"E	30° 6'0.93"N 31°21'16.81"E	30° 5'31.07"N 31°20'20.72"E
5th community	30° 0'58.63"N 31°26'44.47"E	30° 0'20.00"N 31°26'45.48"E	30° 0'58.01"N 31°25'50.44"E	30° 0'20.20"N 31°25'50.36"E

4-1-2 Climate analysis:

Cairo's climate is classified as mixed dry, semiarid mid latitude/arid subtropical/highlands (ASHRAE 2005). Based on 30 years of WMO Station no.623660 records at Cairo International Airport the extreme hot week period lies in between 26th June to 2nd July. The maximum average air temperature T_a is 44.0°C, the maximum average summer RH is 42% and 49% at midday in June and July respectively, the maximum average wind speed is 3.5 m/s in June and July at 74m a.g.l and the maximum average monthly global radiation is 7385, 7316, 6893 Wh/m^2 for May, June and July respectively and the maximum daily direct solar radiation is 773 Wh/m^2 at 13.00 to 14.00 LST on 14th June, fig (4-2/a, b).





Right; Figure (4-2/a): Cairo monthly average meteorology based on 30 years records of WMO Station no.623660 for the hottest day 177 (calculated by Ecotect weather tool) which is the start of the extreme hot week.

Left; Figure (4-2/b): Cairo annual wind frequency based on 30 years records of WMO Station no.623660. N-W, N, and N-E are the dominant wind directions (calculated by Ecotect weather tool).

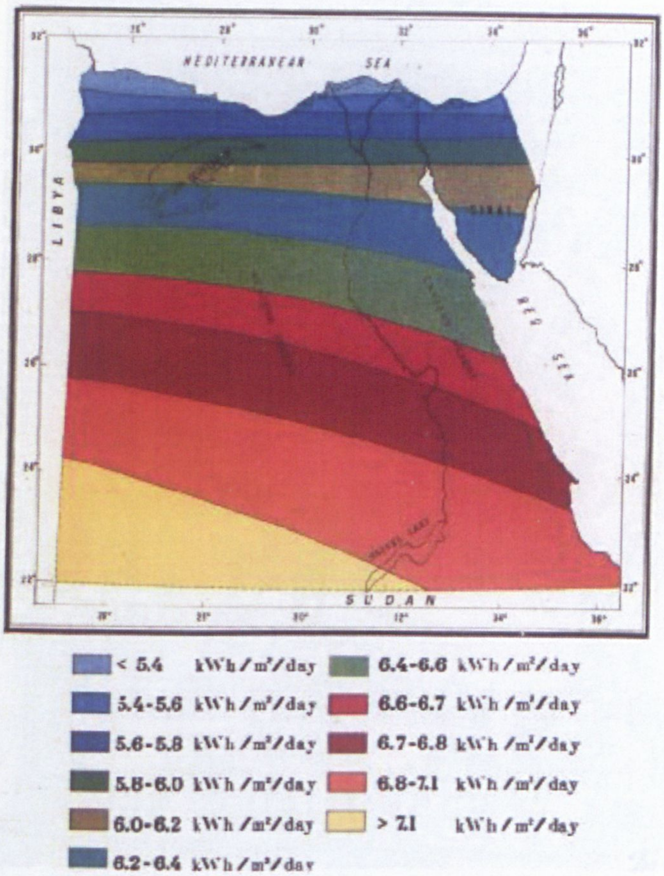


Figure (4-2/c): Global radiation in Egypt, adapted (ANRE 1991).

4-2 The Fifth Community, New Cairo of Egypt:

4-2-1 Historical background:

The Fifth Community is about 5 to 6 neighbourhood s in scale. It lies to the east of the 1st Greater Cairo's ring road at 50 m above Al-Moqtam Mountain as shown in the lower right corner of fig (4-1/a). New Cairo was planned as one of a series of new towns around Cairo to attract population away from metropolitan areas at the start of the transition period of urban planning polices from the post revolution socialist governmental planning to the open market planning 1982, (Donia et al., 2004), (Stewart, 1999), (Stewart and Yin et al., 2004). It was planned as a traditional neighbourhood development, but the non existence of regeneration, environmental and job opportunities policies and auto mobile dependent based patterns increased the load on metropolitan Cairo instead, (Sutton and Fahmi, 2001), (Fahmi and Sutton, 2008) and (El Araby, 2002). Figure (4-3) demonstrates the neighbourhood scale of the Fifth Community.

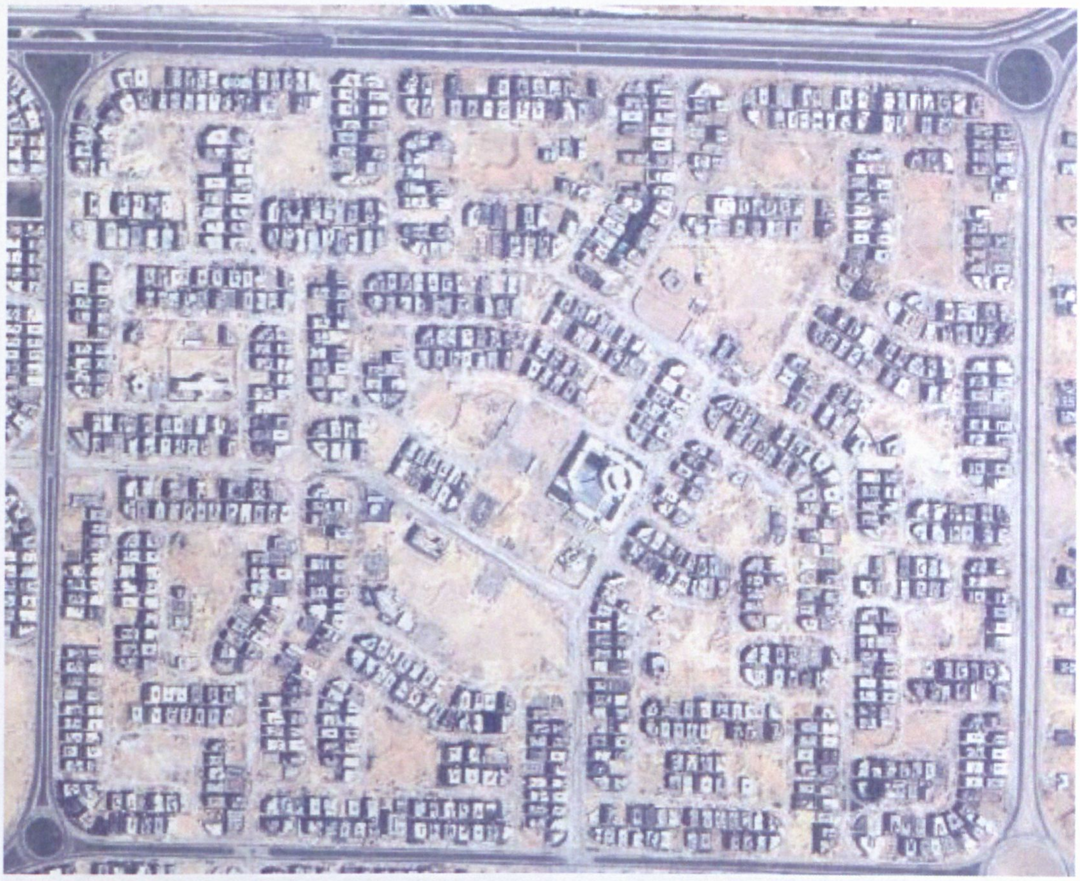


Figure (4-3): 0.6 resolution Quick Bird 2008 satellite image for the 3rd district (neighbourhood scale of about 1 km^2) of the 5th community, the research case no.1, captured for this research work.

4-2-2 Population analysis:

The core of the Fifth Community as the main neighbourhood of New Cairo had a low cost (commercial) ground floor plus four floors of multifamily apartment buildings allocated around the service centre, then high cost multifamily housing apartment buildings were built within service centre urban areas. The rest of the residential land use is single family housing dot fabric patterns that had about 50% converted into multifamily housing dot fabric with a ground floor plus two more floors.

Calculations from 2008 geo databases give an approximate figure about the existing population of the site considering the Egyptian family of 3.75 people on average, based on the population studies and surveys of Egypt till 2006 done by (CAPMAS, 2008). The 5th Community is planned to have almost no self economy generation, i.e. there is no industrial, agricultural or trade economies apart from the daily service facilities; it is just a housing community. This standing point if added to the single family housing can give an idea about the economic situation and income of individuals and families inhabiting 5th Community even after housing needs have converted about 60% of dwellings into multifamily housing as private housing has very expensive prices that are not less than 2000 EGP/m^2 from field surveys done in summer 2007. The calculated site population by ArcGIS estimated conversions of about 60% of the dwellings into multi story family flat housing to replace the single family villa housing that was planned for. Hence, the almost standard 320 m^2 ground floor, leaving almost 1000 m^2/villa and providing 6 flats of about 160 m^2 if converted.

4-2-3 Construction regulations:

Most of single family housing dwellings are 300-400 m^2 of ground floor built area over 600-800 m^2,which is 50% of the plot area. The converted units have been divided into two flats per floor of about 150-200 m^2/flat of a ground plus 2 floors with roof for all of the converted dwellings.

Figure (4-4/a): GIS 3-D modelling for the existing situation by ArcScene built over a Quick Bird 2008 satellite image for the 3rd district (neighbourhood scale of about 1km^2.) of the 5th community, the research case no.1.

The regulations helped produce a dot fabric urban form by stating recesses from all plot area sides 3m from front and both sides then not less than 4m from the back conditioning 50% construction percentage of the plot area, (NUCA 2006), fig (4-4).

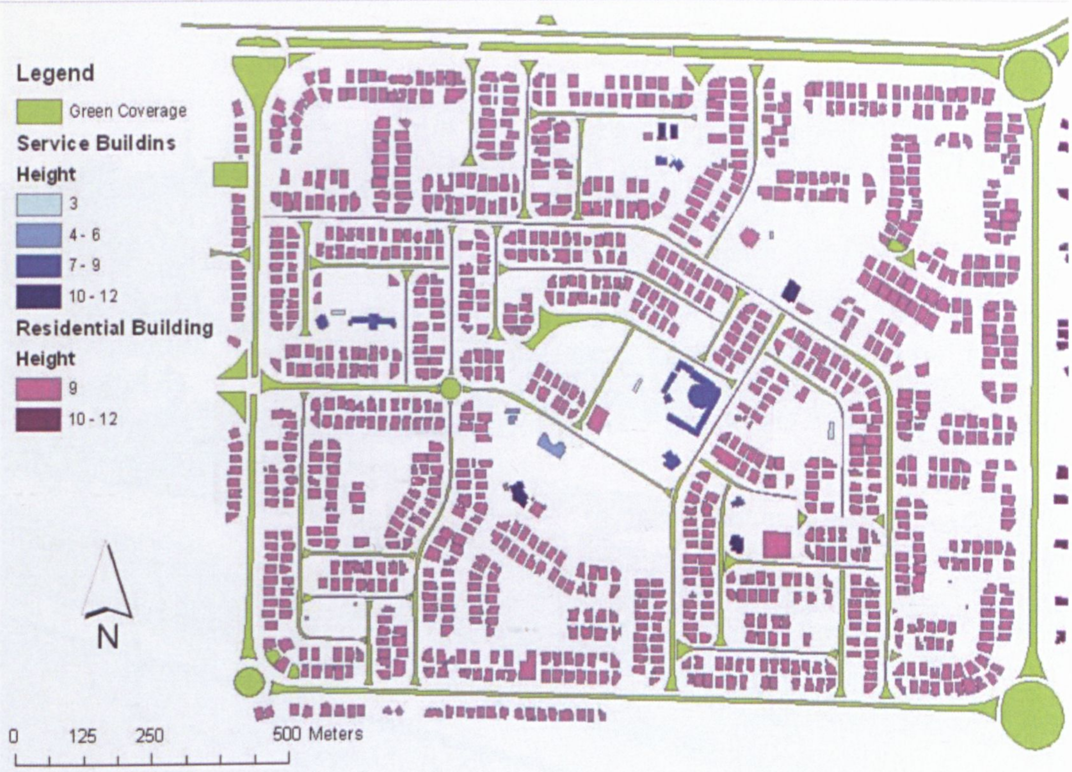


Figure (4-4/b): GIS land use analysis of Fifth Community illustrated with buildings heights in metres.

4-3 Misr Algadida, Metropolitan Cairo:

4-3-1 Historical background:

Misr Al-Gadida was built in the early 20th century as a result of forming the *Cairo Electric Railways & Heliopolis Oases Company*, a partnership between the Belgian investor Edouard Empain and the Egyptian investor Boghos Nubar. The main benefit of this railway was the construction and development of the housing suburb to the northeast of metropolitan Cairo over about 18000 feddans at near the place of ancient Heliopolis, (Heliopolis-Company 2006), fig (4-5).

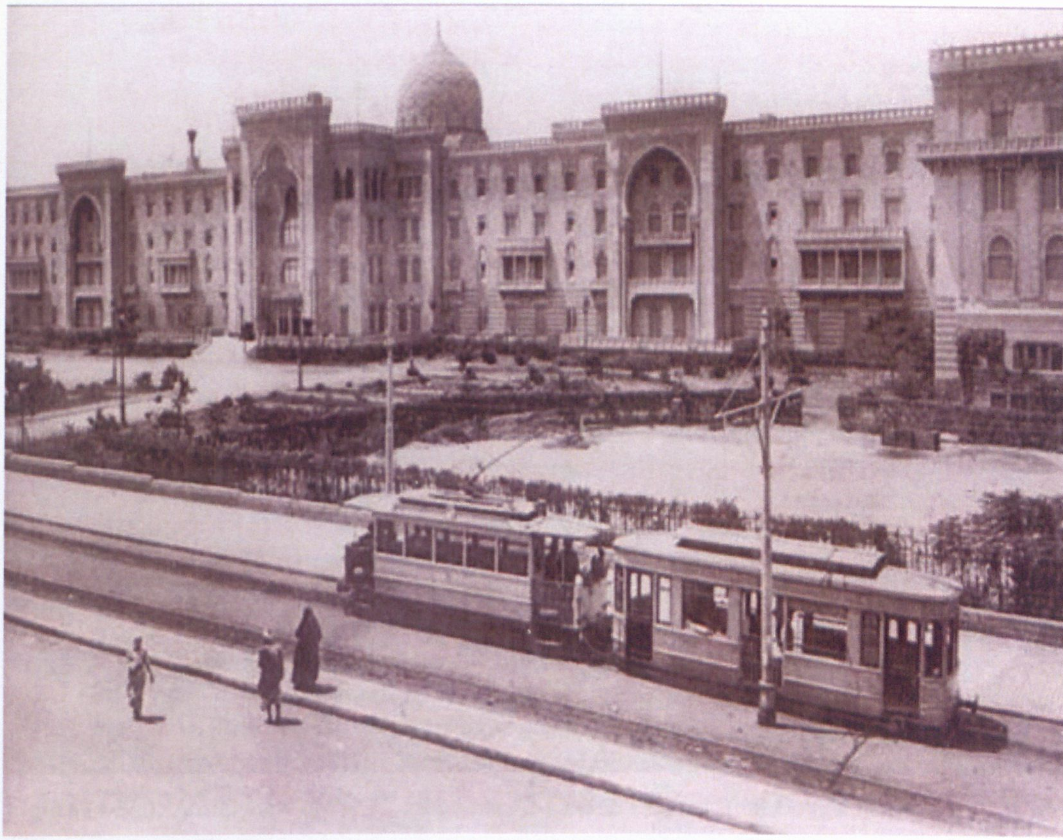


Figure (4-5/a): Heliopolis Palace Hotel before used as presidential administrative palace in the 1980s, adapted from (Raafat 2004).

Figure (4-5/b): Heliopolis downtown 1913, the Palace shown in 4-5/a is highlighted in red and the palace of Edouard Empain is highlighted in blue, adapted from (Raafat 2004).

Figure (4-5/c): Aerial view of the 2nd case Misr Al-Gadida adapted from Google maps.

4-3-2 Population analysis:

Misr Al-Gadida was firstly planned as a north east development for Cairo. It was also only to have a housing function for the improvements at the time regenerated and attracted population, hence administrative and commercial uses generated the local economy of Misr Al-Gadida. Site population calculations are based on 2008 geo databases and on the population studies and surveys by (CAPMAS, 2008) while assuming that each family in the multifamily apartment buildings' site have not less than 120 m^2/flat/dwelling as an average between the medium and upper classes of flat housing areas. In fact, this assumption meets the economic situation and circumstances of the well educated middle class that lives in Misr Al-Gadida. Figure (4-6) illustrates a comparison between the 5th Community and Misr Al-Gadida's urban site population statistics. Misr Al-Gadida population has been calculated by ArcGIS assuming a fixed standard of housing which is 110m^2/flat, which is estimated after (CAPMAS, 2008) rate of crowd of 1.12 person/bed room that means a family of 3.75 persons needs 3.35bedroom/flat. (Law106, 1999) states 3.6×3.6m room as minimum dimensions. In fact older buildings than this specification contains 3×3m rooms, but if considering the large flats' areas of the early 20th century that contained more than

5×5m rooms, the 4×4m room area estimation can be used. Hence, a 3.75persons' family needs are:

1- 3.35 rooms of 4×5m = 67m² sleeping room's area.
2- One 4×4m = 16 m² dining room area.
3- One 4×4m = 16 m² living room area.
4- One 3.0×3.0m = 9.0 m² kitchen area.
5- One 2.5×2.5m = 6.25 m² bathroom area.
6- Net flat area of 114.25 at minimum.
7- Total flat area with staircase and service shoot utilities of about 8m²/flat is approximated to 120 m²/flat for ArcGIS database calculations accepting integers only.

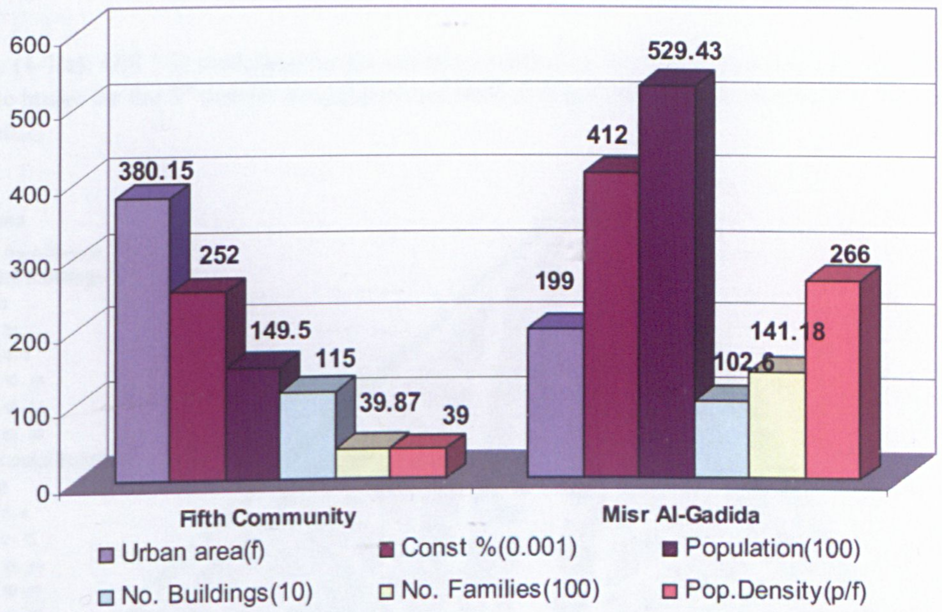


Figure (4-6): Statistical comparison between the Fifth Community and Misr Al-Gadida, the urban area is in Feddans (Feddan = 4200 m²).

4-3-3 Construction regulations:

As Misr Al-Gadida was planned and built over more than a 50 year time period. The construction percentage over plot area varies but commonly is about 60-80% for residential building built before (Law106 1999), restricted to 60% since this law has been issued in 1975 and then modified in 1999. The height of fabric is corresponding to the road it looks at, i.e. the aspect ratio reveals different building' heights as illustrated in fig (4-7). Generally, this allows 1.5 of the road width and a recess from the ownership limits of 2m with no more than 1.2m cantilever of the typical floors from the ground floor.

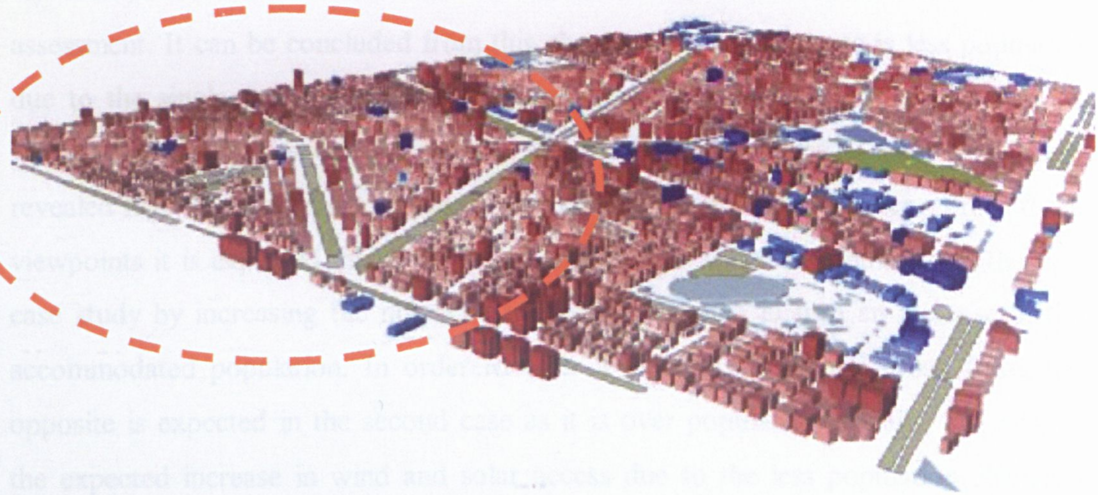


Figure (4-7/a): GIS 3-D modelling for the existing situation by ArcScene built over a Quick Bird 2008 satellite image for the 3rd district (neighbourhood scale of about 1km^2.) Misr Al-Gadida, the research case no.2.

Figure (4-7/b): GIS land use analysis of Misr Al-Gadida illustrated with buildings heights in metres.

4-4 Summary:

Presented and discussed in this chapter, graphical GIS supported illustrations for both of the chosen case studies for the local climate scale thermal performance assessment. It can be concluded from this chapter that the first case is less populated due to the single family dot patterned housing which revealed more wind access as well as more solar access. Contrary, the second case, which is over populated, revealed high rise apartment buildings with more solar and wind shelter. From these viewpoints it is expected that a hybrid urban form will increase population in the first case study by increasing the number of housing units and in turn an increase in the accommodated population. In order to offer a medium population urban form, the opposite is expected in the second case as it is over populated basically, in terms of the expected increase in wind and solar access due to the less population clustered form, there is a question about its thermal performance.

Chapter Five: Comparative numerical assessment

5.1 Method

5.1.1 Simulation tool

As the scope of this research is to design and apply integrated urban passive tools within master planning process of urban developments, there was a need to investigate which method is appropriate to assess alternative urban forms. There was no doubt that field measurements could not be undertaken due to the physical size of the areas to be examined, the large number of meteorological parameters that would need to be measured and the scale of any survey to obtain pedestrian comfort levels. As discussed in Chapter One, the thermal interactions of the urban fabric and vegetation, together with assessing their effects on human comfort and the ambient environment, are very complex. This complexity is partly due to the advanced mathematical and physical models having been developed to assess urban thermal interactions. The conventional framework of neighbourhood planning, as discussed in Chapter Three, is to use the land to accommodate a certain population and to provide sufficient facilities. The prediction of thermal impacts and the sensitive design in a micro urban context can maximize sustainability at this scale in terms of urban comfort and other thermal effects, such an approach has been made possible by the software package ENVI-met.

In previous times urban planning did not need such complicated assessment methods. From the mid 20th century the patterns of urban designs grew in complexity, especially as sustainability became an ongoing issue in the 1990s. Therefore, the use of simulation packages to improve understanding of urban microclimate and energy use and how it might affect design has increased significantly in the last decade.

Among the many models in the field of urban climatology to account for urban environmental interactions, ENVI-met is almost the only software capable of adequately assessing pedestrian thermal comfort, all meteorological parameters and all urban surface and vegetation thermal interactions. It can numerically introduce different soil and plant types with a limited number of inputs and account for solar movement at any location.

Table (5-1) show a brief comparison between available CFD packages that can serve the scope of this research upon and ENVI-met.

Table (5-1): Brief comparison of CFD software serving the scope of the research

Package	Phoenics	Fluent	ENVI-met
Availability	Should be bought; http://www.cham.co.uk/default.php	Through the university network; http://www.fluent.com/solutions/index.htm	Freeware: www.ENVI-met.com
Computational resources	Super computer for large models simulations.	Super computer for large models simulations.	Only highly configured PC for large models simulations.
Built environment modular	3-d graphical user interface	3-d graphical user interface, but no consideration for location or solar path.	Simple through 2-D graphical user interface, for fabric, vegetation, location and solar path
Core calculation model	All types of radiant interactions except surface temperature, wind flow and plants but without its complete thermal effects. Also it doesn't include a soil model.	Heat transfer and wind flow simulation through outdoor environment without considering short-wave radiation. Plants can be coded but without its complete thermal effects.	All types of radiant interactions, wind flow, plants, soils and pm10 and gaseous emissions but without considering their thermal effects.
Input data	Input formulae and graphical user interface	Input formulae and graphical user interface	Data bases and graphical user interface
Output data	All meteorological, but not for vegetation , soil or T_{mrt}.	All meteorological, but not for vegetation , soil or T_{mrt}.	All meteorological, vegetation and soil parameters and T_{mrt}.
Validation	Yes	Yes	Only for radiation , T_{mrt}, RH whereas the package has been used by many research studies
Comfort prediction index	No	No	PMV

5.1.2 ENVI-met 3.1 Capabilities

ENVI-met is a non-hydrostatic prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. It is a more comprehensive package than can be found in dedicated CFD package for fluid dynamics simulations (Ali-Toudert and Mayer 2006). ENVI-met can simulate the surface-plant-air interactions within urban environments with a typical resolution of 0.5 to 10 m in space and 10 sec in time for built environments from microclimate scale to local climate scale at any location. Moreover, the combination of biometeorological outputs from ENVI-met gives a deep understanding of climate in the urban canopy layer, such as presented by (Ali-Toudert and Mayer 2007a; Ali-Toudert and Mayer 2007b). The model includes the simulation of flow around and between buildings and the exchange processes of heat and vapour at the ground surface and at walls. ENVI-met is a freeware program and is under constant development (Bruse 2008; Bruse 2009). The model depends on finite difference for the 3-D numerical modelling and its architecture is built upon a number of connected sub-models representing fabric surface-plant- soil-air relations.

ENVI-met model architecture has almost all the algorithms of a CFD package such as the Navier-Stokes equations for wind flow, E-ε atmospheric flow turbulence equations, energy and momentum equations and boundary condition parameters. But it is more developed than a specialist CFD package as it simulates the soil-plant-surface-air relations by applying a numerical model for each. Furthermore, it gives an assessment for outdoor comfort levels following (Jendritzky and Nübler 1981) based on human biometeorology within urban environment along with the simulation meteorology input. Urban canyon heat budgets and short-wave radiation fluxes at a model point (x, y, z) are based on the reductions that the sky view factor, SVF, surface albedo and the leaf area index, LAI, of plants at any height z in the model. Long-wave radiation fluxes are calculated at a point (x, y, z) from the wall's horizontal long-wave emissions, coming up from ground surfaces and coming down either from the sky or as a part of the trapped heat by plant canopies. These are calculated using each surface or plant leaf temperature, emissivity, absorptivity and the Stefan-Boltzman constant. Surface temperatures are calculated using the balance of all net-wave radiation and heat fluxes from both hemi spheres.

The ENVI-met vegetation model is formed over one-dimensional column with height z_p in which the profile of a tree's leaf area density, LAD, represents the amount and the distribution of leaves (Bruse 2008). The distribution of roots within the soil system is represented by the root area density, RAD, from the surface towards the root depth $-z_r$. In this way all types of vegetation can be modelled. The vegetation model is formed from four sub-models; the first is the turbulent fluxes of heat and vapour sub-model that solve interactions of temperature, humidity and air movement between air and tree foliage. The second solves interactions of evaporation and transpiration of water from soil through a plant that is affected with its stomata resistance r_s. Differing from grass to tall trees, it is simply the number of stomata of a plant's green leaves per unit area that describes the resistance transpired water can face as it evaporates through leaves. Hence, stomata resistance depends on short-wave radiation and the soil water. The third sub-model is a steady state leaf energy budget depending on the foliage albedo, a_f and light transmission factor, tr_f that control net short-wave radiation absorbed by plant. The fourth sub-model calculates the mass of water transpired from soil depending on the soil hydraulic diffusivity through its layers, so that evapotranspiration effects can take place if stomata resistance and soil water allow that. Detailed information and equations can be found in (Bruse 2008).

The package has its own numerical data base for some plant LAD profiles that is used when simulating the native environment of these plants and depends on analytical approaches that can help in obtaining the LAD distribution of other plants, especially if the LAI is known (Bruse 2008). The same concept is used for the soil model's thermal and hydrological properties. The soil 1D model distributes its properties over three layers (0- 20 cm, 20-45 cm, and 45-175 cm) where each layer represents a soil type. This answers why ENVI-met has been preferred for the numerical simulation of new trees. However, the foliage and soil characteristics of hot climate regions such as Egypt are not represented in the plant or soil data bases in the software. The data bases needed 10 LAD values to be distributed over the tree normalized height, and the cool surfaces properties were modified in the soil data base. More details about ENVI-met's governing equations, model architecture and course of simulations can be found in (Ali-Toudert 2005; Bruse 2008). The software is now in its second beta version after work presented by (Fahmy et al. 2010) found an LAI bug in the first beta version that prevented the interception of direct radiation through different trees types. That is why work presented in this research has used the pre-beta version 3.1.0.11.

5.1.3 ENVI-met 3.1 Limitations and validation

Although ENVI-met mainly uses a 3-D multi model (turbulence, vegetation, soil, etc), it also uses the 1D models to transfer all data entry for wind speed and direction, air temperature, humidity and turbulence quantities. Despite the developed capabilities of ENVI-met, there still more improvements are needed (Ali-Toudert 2005). Specifically, the keeping of input data entry fixated at the model boundary conditions using the so called 1D. It applies a logarithmic law to calculate the wind profile based on the wind speed at 10m above ground level and on the roughness length. It also transfers the initial air temperature and the model humidity using the specific humidity at 2500m and the relative humidity at 2m a.g.l. All calculations are eventually based on these initial transferred inputs that are kept fixed during simulation. Consequently, the actual site hourly conditions are not related to simulation outputs except humidity that can have the same trend as measured data if the measurement site is dry. Theoretically, it could be possible to compare ENVI-met results for air temperature *Ta*, wind speed *V* and relative velocity *RH* in a mid-latitude location with measurements if the meteorology at the boundary conditions were adjustable, height of simulated records within urban canopy layer equal to the corresponding measured data and if these heights assure blending between the roughness sub-layer and the urban canopy layer in both sites (Oke 2004). Future development of the software could consider forced daily measurements which are kept constant as mentioned before. Therefore, it is needed to use a representative daily input, and thus for a non-moderate or a coastal site of daily *Ta* differences over 12°C, ENVI-met underestimates temperature by night and overestimates by day and cannot predict a strong marine breezes which affect surface sensible heat calculations.

Figure (5-1) illustrate RH validation done by (Fahmy et al. 2010) who found that it worth plotting results of RH from simulations with that of airport meteorological station as they were found to have nearly the same profile and ranges as if the trees did not exist in the model at all. It has been recognized that evapotranspiration did not take place effectively because there was not enough water content in the soil under the trees. The water content after all simulations in this study ranged only from 0.08-0.14 m^3 / m^3 *(cubic meter of water in each cubic meter of soil) at different depths due to the soil's reduced humidity input, i.e. almost no water has been applied for trees and hence environment has been simulated as if there are trees and vegetation which allowed RH comparison with open horizon measurements of at Cairo International Airport weather station.*

However, one of the most significant limits is calculating the heat stored in building is that the heat transferred through walls is calculated by conduction using wall U-values. Hence, the surface temperature, along with the long-wave radiation from buildings are overestimated by day and underestimated by night meaning that the nocturnal cooling effect cannot be studied fully even for urban forms designed to allow more night release.

Moreover, due to some simplification assumptions, global radiation is overestimated. (Ali-Toudert 2005) used an adjustment factor of 0.84 to close the gap with measured radiation values. In turn, the total radiant exchanges occurring for a standing person cannot be accurately estimated which is the result of an overestimate of comfort levels.

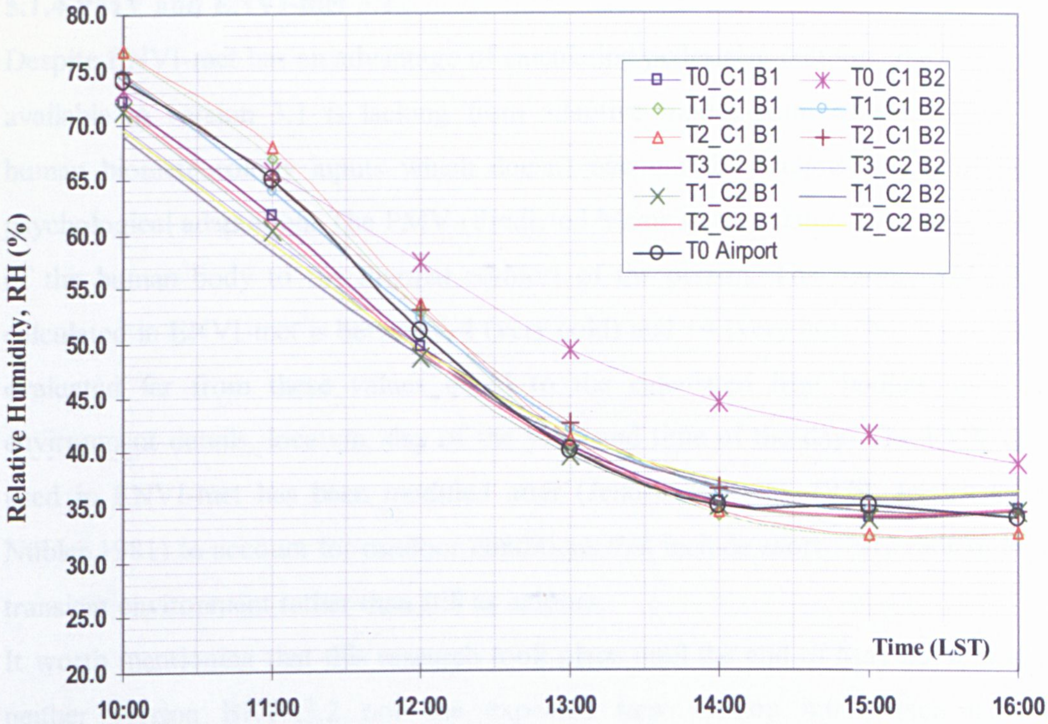


Figure (5-1): RH measured at Cairo Airport in comparison with output from simulated cases, adapted from (Fahmy et al. 2010).

An adjustment factor of 0.84 was estimated by (Ali-Toudert 2005) for global radiation calculated by ENVI-met to equal measurements in hot climate of Beni-Isguen, Algeria which can be refereed to as a validation regardless the 0.14 factor difference between measured and simulated.

Nevertheless, for comparing design scenarios the relative prognosis of microclimatic modifications due to urban environments to assess outdoor human thermal comfort and to give urban planning and design implications, it is possible. In version 4.0 of the software, it is expected to allow forcing hourly inputs, calculating wall heat storage, offer 3-D views for the model area and other improvements (Bruse 2009; Huttner and Bruse 2009). Therefore, it need not only be used as an urban planning and design decision support tool but can also be coupled with either a meso-scale atmospheric model for bigger scale climate investigations, or with an indoor energy model to predict consumption and climate change effects. The later is theoretically presented in section 5-4-3 of this study. An extended list of ENVI-met advantages and disadvantages can be found in the master thesis of (Spangenberg 2005), but some of V3.0 disadvantages have been sorted out in V3.1.

5.1.4 PMV and ENVI-met 3.1

Despite ENVI-met has an advantage of calculating pedestrian comfort, the PMV scale available in version 3.1 is lacking from adaptive model point of view as it fixes human biometeorology inputs which doesn't account for acclimatization or human psychological adaptation. The PMV (Predicted Mean Vote) relates the energy balance of the human body to the thermal comfort of the person. The normal PMV value calculated in ENVI-met is between -4 (very cold) and +4 (very hot), but it can also be evaluated far from these values owed to the calculated heat budget upon built environment details, location, day of the year, and time of the day. The PMV model used in ENVI-met has been modified after (Jendritzky et al. 1979; Jendritzky and Nübler 1981) to account for outdoor conditions that include short-wave radiations and transient environment rather than still as indoors.

It worth mentioning that this research took place until the end of May 2010 at which neither version BETA3.2 nor the expected new version 4.0 (which uses the physiological effective temperature, PET as comfort index) of ENVI-met have been issued. Moreover, regardless that T_{mrt} is calculated by the software, it cannot be used as a comfort scale as it doesn't account except for the received all-wave radiation by a pedestrian not for *RH* or for wind (Ali-Toudert and Mayer 2006).

5.2 Simulation course:

5.2.1 Parameterization

In order to assess both whole site thermal performances against the passive design tools used to design urban patterns, simulations were held for 12 hour periods from 6.00-18.00 LST on the 1st of July as a representation for the summer period. It is the extreme summer day analyzed by ECOTECT5.6, which is expected to result in high radiant interaction values. It is a research interest of this study to investigate extreme conditions. However, the choice of day is not critical as results are almost not specifically related to real conditions. As this study is conducted as a comparison between base cases and suggestions it did not matter which day is used, the extreme of 1st July or the typical (7th June). Results were recorded at 1.6m height all over the model area to represent a pedestrian comfort point of view. The thermally affected height of a pedestrian from 1.2-1.75m a.g.l. is acceptable - 1.2m a.g.l. was used by (Ali-Toudert and Mayer 2007b) and 1.4m a.g.l. used for measurements in Freiburg, also by (Ali-Toudert and Mayer 2007a). The cumulative parameter assessed in this study is the PMV difference and reductions between cases compared at specific time so that overestimations can be discarded regardless what is acceptable for comfort and what is not. Despite the software overestimations, it can give an idea about pedestrian comfort. The mean radiant temperature, T_{mrt}, as it stands for all types of radiation from the six directions of both hemi spheres; i.e. from direct and diffuse short wave radiations, all long wave radiations from the sky, from surrounding built environment, trapped by trees canopies as well as emitted from ground. Ground finishing materials are fixed in all simulations to avoid different emissivities, tables 2 and 3. T_{mrt} is defined as *'the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure'* (ASHRAE 2005). Moreover, a complete set of meteorological parameters air temperature T_a, wind speed V and the relative humidity RH have been recorded for both cases to understand the local climate conditions upon which a comfort level has been recorded and with which further studies took place and will be presented in section 5.5.2.

In addition, to understand the detailed effect of the urban fabric and urban trees sheltering effects, direct and diffuse short-wave radiations $S_{w.dir}$ and $S_{w.dif}$ are compared with that of free horizontal surface radiations recorded at the Cairo International Airport weather station. To understand fabric effect on stored and emitted heat, the air-surface long-wave radiation fluxes downward (trapped) from trees canopies $L_{v}\downarrow$ and from building walls $L_{w\leftrightarrow}$, are compared with those of base cases in each site. $L_{v}\downarrow$ is not calculated in ENVI-met a.g.l. so, although $L_{w\leftrightarrow}$ can be calculated at any height, both parameters were extracted at the surface. Output data extraction method will be presented in section 5.2.4.

5.2.2 Data entry

The fabric finishing material is represented in ENVI-met by the thermal conductance, U-value, and the albedo. These parameters are used as data entry for walls and roofs, tables (5-2), (5-3) and (5-4). Buildings geometry were obtained from GIS Geo databases with digital maps bought from Globe-Telecom Company based in Cairo, accompanied with 0.6m high resolution Pan-sharpened colored QuickBird2008 satellite imageries. Total floor height is approximated to 3.0m in both cases.

Table (5-2): Abbreviations used in simulations.

Symbol	Meaning
B	Base case
DS	Design suggestion
C1	Case no.1; Fifth Community
C2	Case no.2; Misr Al-Gadida
T0	No Trees; the base case situation of site one
TE1	Ficus Elastica (Indian rubber plant), with LAI=1.
TE2	Peltophorum Pterocarpum (Yellow Poinciana), with LAI=1.
TE3	Ficus Nitida, with LAI=1.
TC1	Ficus Elastica (Indian rubber plant), with LAI=3.
TC2	Peltophorum Pterocarpum (Yellow Poinciana), with LAI=3.
TC3	Ficus Nitida, with LAI=3.

Table (5-3): Inputs of C1 (Oke 1987; HBRC 2003; Akbari et al. 2006; Bruse 2008; DOE 2009).

No.	Parameter	Value
1	*Ta*	301.95 K
2	*RH*	59%
3	*V*	3.5 m/s at 10m height
4	Ground temperature	301.65 K from 0-0.5m and 297.45 K from 0.5-2m
5	Ground humidity	BC & DS1; 20% from 0-0.5m and 30% from 0.5-2m DS2 & DS3; 70% from 0-0.5m and 80% from 0.5-2m
6	Roughness length	0.15
7	U value Walls	1.7 w/m^2.K
8	U value Roofs	2.2 w/m^2.K
9	Albedo Walls	0.25 for all except DS3; 0.15
10	Albedo Roofs	0.15 for all except DS3; 0.40
11	Albedo Pavement	0.40
12	Albedo Asphalt	0.20 for all except DS3; 0.50
13	Ground Emissivity	0.90
14	Human walking speed	1.1 m/s
15	Pedestrian Clo.	0.50 (1Clo=0.155 m^2.K/w; i.e. Light summer cloths)
16	Lateral boundary scale	5 times the highest building for all C1 master plans assessed
17	BC resolution	5.70 × 4.56m
18	DS1 resolution	5.70 × 4.56m
19	DS2 resolution	6.50 × 5.80m
20	DS3 resolution	6.50 × 5.80m

Table (5-4): Inputs of C2 (Oke 1987; HBRC 2003; Akbari et al. 2006; Bruse 2008; DOE 2009).

No.	Parameter	Value
1	*Ta*	301.95 K
2	*RH*	59%
3	*V*	3.5 m/s at 10m height
4	Ground temperature	301.65 K from 0-0.5m and 297.45 K from 0.5-2m
5	Ground humidity	BC & DS1; 20% from 0-0.5m and 30% from 0.5-2m
		DS2 & DS3; 70% from 0-0.5m and 80% from 0.5-2m
6	Roughness length	0.15
7	U value Walls	1.7 $w/m^2.K$
8	U value Roofs	2.2 $w/m^2.K$
9	Albedo Walls	0.25 for all
10	Albedo Roofs	0.15 for all except DS3; 0.50
11	Albedo Pavement	0.67 for all
12	Albedo Asphalt	0.20 for all except DS3; 0.50
13	Ground Emissivity	0.90
14	Human walking speed	1.1 m/s
15	Pedestrian Clo.	0.50 (1Clo=0.155 $m^2.K/w$; i.e. Light summer cloths)
16	Lateral boundary scale	8 times the highest building for all C2 master plans assessed
17	BC resolution	5.0 × 5.0m
18	DS1 resolution	5.0 × 5.0m
19	DS2 resolution	5.0 × 5.0m
20	DS3 resolution	5.0 × 5.0m

5.2.3 Tree Modelling

ENVI-met has its own numerical data base for some plant *LAD* profiles that is used when simulating the native environment of these plants and depends on analytical approaches that can help in obtaining the *LAD* distribution of other plants, especially if the *LAI* is known (Bruse 2008). This is one of the answers why ENVI-met has been decisively preferred in this research. As the foliage characteristics of hot climate trees, such as the Egyptian trees investigated in this study, are not represented in the plant data base of the software, the data base needed 10 *LAD* values to be distributed over the tree normalized height. Hence, the *LAD* values for 10 slices of each tree had to be generated to introduce these new trees to ENVI-met and to study their thermal performance foliage based differences.

Leaf area density spatial distribution are introduced for ENVI-met simulations in two steps (Bruse 2008). First, the minimum *LAD* of the tree is calculated using software compiled in Fortran by authors based on the empirical *LAD* model of (Lalic and

Mihailovic 2004). This model was solved 10 times to produce *LAD* values at different heights of the tree using the tree height h, the maximum leaf area density L_m, and the tree canopy corresponding height z_m. In the second step, *LAD* results were added to ENVI-met plants database to represent the 3-D canopy of these trees. Consequently, these trees were introduced to the model area and simulated, regardless of the many ways of performing field measurements of *LAI*; it was a research question to investigate modelling of a tree canopy in absence of measured value. The maximum LAD, L_m, needed in the *LAD* model have been derived by assuming *LAI* value. In this respect, the ground level shape of a tree shadow that depends on the light transmission profile has been suggested regarding tree plantation objectives. Plantation objectives means the purpose or the aim of planting a tree i.e. is it ornamental, functional, etc (Arnold 1980; Trowbridge and Bassuk 2004)? In this work the objective is to produce maximum ground shadow at peak time in Cairo. Eventually, a specific thermal performance and modifications towards a tree microclimate can make it more preferable to another one.

With regard to the solar position, at the peak time (13.00 LST) the solar altitude reaches 83.3° in the extreme hot week (26th of Jun – 2nd of July), which is assumed to be vertical, so that ground shadow almost equals the plantation area or in another word, the upper leaves area, fig (5-2).

By definition, *LAI* can be represented as following:

$$LAI = A_L/A_P \qquad \text{Eq. 13}$$

A_L is the upper leaves area (m^{-2}).

A_P is the tree ground planting area (m^{-2}).

At peak time if the shadow is solid, then A_P should almost equal the projected ground shadow, A_g. Therefore;

$$LAI = A_L/A_g \qquad \text{Eq. 14}$$

A_g is the maximum projected ground shadow of the tree at maximum solar altitude, (13.00 LST).

In other words, the least value for *LAI* to produce a solid ground shadow at maximum solar altitude of nearly 90° (peak time), is when the upper leaves area equals that of the shadow area, i.e. if the tree is modelled it will produce a solid shadow with the minimum amount of leaves; or

$$LAI = A_L/Ag = A_L/Ap = 1 \qquad \text{Eq. 15}$$

In relation to the site investigated, this means a good approximation of applying this *LAI* value when the altitude is 83.30° of the simulated day, the 7th of June, fig (5-2). Hence L_m of the minimum *LAI* of maximum shading effect can be calculated from the model equation as follows;

$$LAI = \int_0^h L_m \left(\frac{h - z_m}{h - z} \right)^n . \exp\left[n \left(1 - \frac{h - z_m}{h - z} \right) \right] .dz \qquad \text{Eq. 16}$$

Substituting L_m in the following equation, so that *LAD* can be calculated for any z;

$$LAD = L_m . \left(\frac{h - z_m}{h - z} \right)^n . \exp\left[n \left(1 - \frac{h - z_m}{h - z} \right) \right] \qquad \text{Eq. 17}$$

h ; is the total height of the tree (m).

z_m ; is the canopy height at which *LAD* is the maximum, i.e. L_m (m).

z ; is the height of *LAD* slice (m).

n = 6 if $0 \geq z \geq z_m$, and 0.5 if $z_m \geq z \geq h$

A compiled FORTRAN software solved equations 17 and 18 to automatically record *LAD* values needed for the ENVI-met database. Moreover, for any tree, if h, L_m, and z_m do not ensure that $LAI = 1$, this means that the ground shading will be filtered, rather than dense or solid, and the tree will transmit larger amounts of radiation. Thus, $LAI = 1$ can be used as a benchmarking reference value for urban trees of semiarid mid latitude regions such as Egypt, where solar attitudes are close to 90° and the shadow area will be almost equal to the planting area. Other foliage parameters in the original database, inputs regarding foliage characteristics, materials and soil types for both cases are fixed to allow only a comparison of thermal performance based on the differentiated *LAD* values and sites details. In this way, trees can be modelled without *LAI* or *LAD* sources for specific species even without measurement especially for the research circumstances that did not allow having real LAI measurements; however, this LAD generator software accepts measured LAI value.

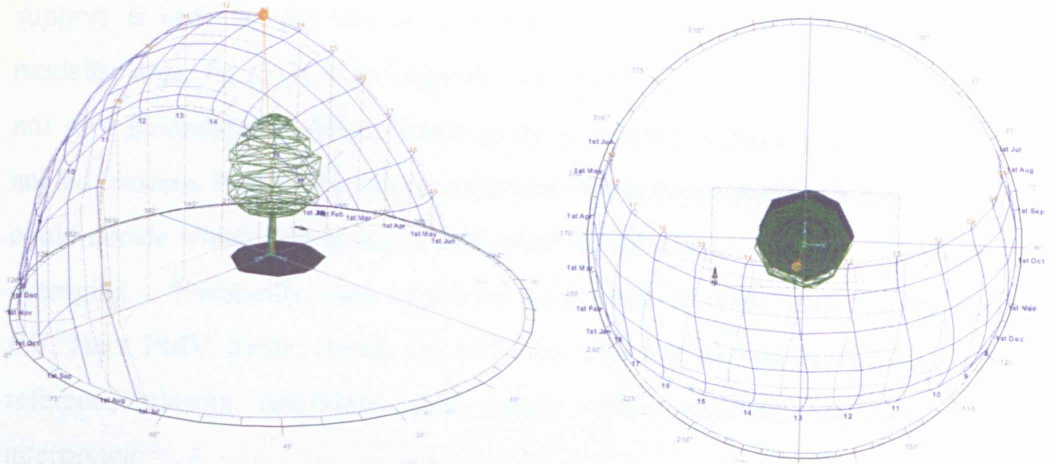


Figure (5-2/a, b): Schematic model by ECOTECT 5.6 for the Yellow Poinciana (following Shahidan et al., (Shahidan et al. 2007)) to indicate shadow of solar altitude of 82.40° on the simulated day, the 7th of June at peak time of 13.00 LST, which is almost equal plantation ground area; i.e. the least LAI should be 1, published in (Fahmy et al. 2010).

5.2.4 PolygonPlus and data extraction

As ENVI-met calculates and record of all the parameters described above for each grid in the model, it was required to investigate how to generate a value for each parameter to represent the whole simulated urban site. By this way, a mean value for the urban site considering patterns details can be more representative in further studies rather than measurements from a far away weather station that site of which may have different urban details, even if a refinement has been made by (METEONORM 2009). Moreover, expected software developments to force ENVI-met to have weather data files makes it a better weather data generator and thus more refined data can be derived for not only comfort based urban planning but also for indoor energy studies as described by (Fahmy et al. 2009). However, ENVI-met is capable of extracting output data in a comma delimited file extension which contains all model area grids coordinates associated with each grid parameter value. The mean values of all the required parameters from 06.00-18.00 LST were averaged from these extracted outputs for only outdoor grids using a simple program written in Visual Basic program called PolygonPlus. It was designed to do two jobs; first to eliminate output data outside the urban area which is included in the extracted output files, and secondly to eliminate the fabric grids from the grid outputs selected inside the urban area so that after both steps it can calculate any parameter mean value for only urban grids inside the specific area. This is designed because the ENVI-met modeller should have all the rectangular area in the modeller built, whereas available GIS data support is only for the site area which represents only a rotated polygon in the modeller area, fig (5-3) is an example. To ease modelling in ENVI-met, which does not give flexibility for oblique fabric grids, a rotation is made in order to allow right angled clusters. PolygonPlus code contained that polygon perimeter equation so that it could decide which grid is inside and which of these is an outdoor to be selected for averaging. Eventually, each simulated hour mean of urban grid outputs for *T*a, *V*, *RH*, *T*mrt, PMV, *S*wdir, *S*wdif, *L*v↓ and *L*w↔ could be plotted to represent local scale reference climate conditions, and hence urban planning implications can be interpreted.

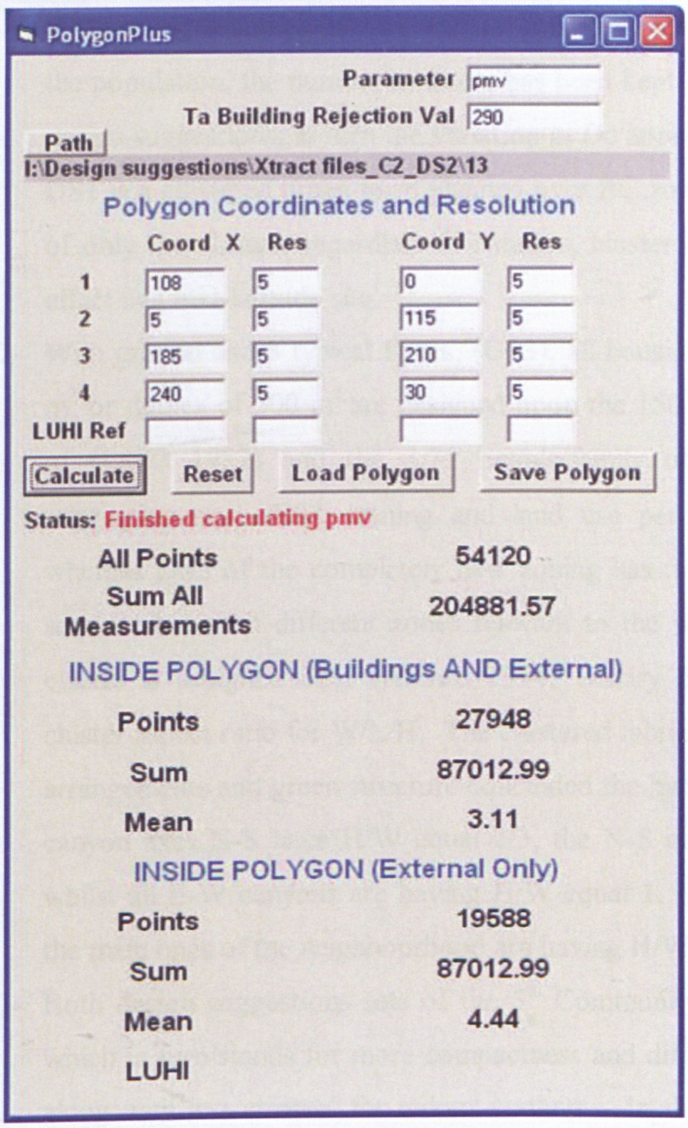


Figure (5-3): Graphical user interface of PolygoPlus that has been developed by the research to calculate meteorology means from ENVI-met extracted files for whole neighbourhood scale.

5.3 Urban form

5-3-1 Fabric

1- In both cases there were two alternatives compared with the base case. Alternatives offered different housing types with more responsive clustered form, green coverage and urban tree arrangements, fig (5-4). This medium population based hybrid form design concluded in different degree on compactness, different degrees of diversity and comfort levels. Figure (5-5) show different housing design and heights of the housing units applied. Modifications that will take place for the cases are theoretical i.e. it would not be applied due to many complications. They have been made just for the research purposes. Following (Fahmy and Sharples 2009a), and to limit the variation of urban form *Dc* to only the population, the number of floors has been kept the same as base case BC in all design suggestions; in turn the variation in *Dc* appear in terms of the built up area. DS1 is a clustered urban form planned over BC zoning in order to study the effect of only the clusters regardless orientation, cluster closure ratio or the GreenSect effect in a mid-latitude site.

2- With ground and 3 typical floors, (G+3), all housing units either single flat of 150 m^2 or duplex of 300 m^2 are designed upon the 150 people/feddan population limit of (Law3 1982) and the 3.75 people/family of (CAPMAS 2008). Design suggestion no.1, DS1, zoning and land use percentages are the same as BC whereas DS2 of the completely new zoning has the same land use percentage of services but with different zones relevant to the whole form of DS2. The DS2 cluster is designed after (Ahmad 1994; Waziry 2002) who argued for 1:3:1.3 cluster aspect ratio for W/L/H. The clustered fabric form, together with urban tree arrangements and green structure concluded the hybrid form of DS2 and DS3 with canyon axes N-S have H/W equal 2/3, the N-S green shaded canyons H/W is 1 whilst all E-W canyons are having H/W equal 1. Among the N-S canyons, only the main ones of the neighbourhood are having H/W equal 2/3.

3- Both design suggestions sets of the 5th Community provide for more population which in turn stands for more compactness and different pedestrian comfort levels along with less stresses for indoor cooling. In the Misr Al-Gadida case, design sets go for reduction in population density which is limited theoretically by (Law3 1982) to the boundary of 150 p/f.

4- (Priyadarsini et al. 2008) argued that under low wind speed circumstances, allocating strategic some high rise buildings can enhance canyons air flow. Hence, increasing heights of five cluster groups has been applied for differing canopy layer height, Z_h. These heights are multi story buildings (residential, commercial and administrative) which, on another hand, can cope with more diversity, and mixed land uses. Locating these four cluster groups was based on three criteria; first, to be around the neighbourhood civic centre, and to be served by the centre services. Second these clusters help mixing ISL winds with the UCL along with generating advective movement which would not be more than an alleviation source as average wind speeds measured for all summer time are less than 2m/s. Third, to help generating leeward vortices provided that windward angle of attack is not parallel with canyon axes, which is already the case as the high building perpendicular to the north prevailing wind direction fig (5-4/c, f).

5- The slope of the local urban plots examined in both base cases will be neglected because it tends to be horizontal. The network in BC1 is a hierarchical grid even in C1DS1 and C1DS2, whereas it is hierarchical radial in BC2 and hierarchical gird in C2DS1 and C2DS2. This is to allow as much tunnelling effect as possible.

Figure (5-4/a, b, c): Master plans of BC1, C1DS1, C1DS2 and C1DS3 from upper right, left and down respectively; buildings in grey, grass in light green and trees in dark green. The red ellipses indicate the location of the high buildings used to help ISL-UCL mixing along with generating canyons' vortices.

Figure (5-4/d, e, f): Master plans of BC2, C2DS1, C2DS2 and C2DS3 from upper right, left and down respectively; buildings in grey, grass in light green and trees in dark green. The red ellipses indicate the location of the high buildings used to help ISL-UCL mixing along with generating canyons' vortices.

Table (5-5): Housing design and land use statistics of C1 and C2

	Case Name	Urban area in feddans	Green coverage %, A_g	Tree type, T_p and L_m	Cluster closure ratio;	Cluster aspect ratio; H/W/L	Urban fabric %, A_c	Average no. of site floors, n_f	Degree of compactness, D_c	Total population in persons	Population density in p/f
1	BC1	380.15	0.368	TE3, 0.022, 0.62	------	------	0.252	3.171	0.799	14950	039
2	C1DS1		0.291	TE1, 0.146, 0.138	various	various	0.299	3.911	1.169	46662	123
3	C1DS1_Dc		0.291	TE1, 0.146, 0.138	various	various	0.299	4.610	1.378	55004	145
4	C1DS1_Lm		0.291	TC2, 0.146, 0.285	various	various	0.299	4.610	1.378	55004	145
5	C1DS2		0.476	TC1, 0.145, 0.414	3.47	1:1.3:3	0.310	4.077	1.264	50448	133
6	C1DS2_Dc		0.476	TC1, 0.145, 0.414	4.27	1:1.6: 3	0.310	4.968	1.540	61473	162
7	C1DS2_Lm		0.476	TC2, 0.145, 0.285	4.27	1:1.6: 3	0.310	4.968	1.540	61473	162
8	BC2	199.0	0.105	TC3, 0.123, 1.86	------	------	0.412	4.920	2.027	52943	266
9	C2DS1		0.273	TC1, 0.077, 0.414 + TC3, 0.111, 1.86	various	various	0.327	4.006	1.310	27372	138
10	C2DS1_Dc		0.273	TC1, 0.077, 0.414 + TC3, 0.111, 1.86	various	various	0.327	4.845	1.584	33104	166
11	C2DS1_Lm		0.273	TC2, 0.188, 0.285	various	various	0.327	4.845	1.584	33104	166
12	C2DS2		0.465	TC1, 0.125, 0.414	3.47	1:1.3:3	0.318	4.296	1.366	28545	143
13	C2DS2_Dc		0.465	TC1, 0.125, 0.414	4.27	1:1.6: 3	0.318	5.237	1.665	34798	175
14	C2DS2_Lm		0.465	TC2, 0.125, 0.285	4.27	1:1.6: 3	0.318	5.237	1.665	34798	175

- In each abbreviation; letter C stands for case, BC for base case and DS for the design suggestion. T_p and L_m stands for the tree urban coverage and its max. LAD.
- No. of people/ family is calculated as 3.75 (CAPMAS 2008). In all design alternatives except base cases, Family no. of flats is also calculated as 150 Sq.m/flat/family. Floor height as 3m. Feddan=4200Sq.m.
- Facilities buildings at service civic centre are 10 m in both C1DS1 and DS2 whereas 13 m in both C2DS1 and DS2 to increase the compactness degree without increasing site population assuming that more facilities are needed.
- The actual residential land use can be calculated after extracting 33% for the network and green coverage as (Law3 1982) tells, also after extracting the civic buildings areas.
- For URPLA comfort model purposes, suffix Dc in the case name means more compactness. For example, C2DS1 has 13m height residential buildings, C2DS1_Dc applies 16m instead. For C2DS1_Lm means using tree TC2 with LAI=3, instead of using tree TC1 or TC3 of also LAI=3, table (5-2).

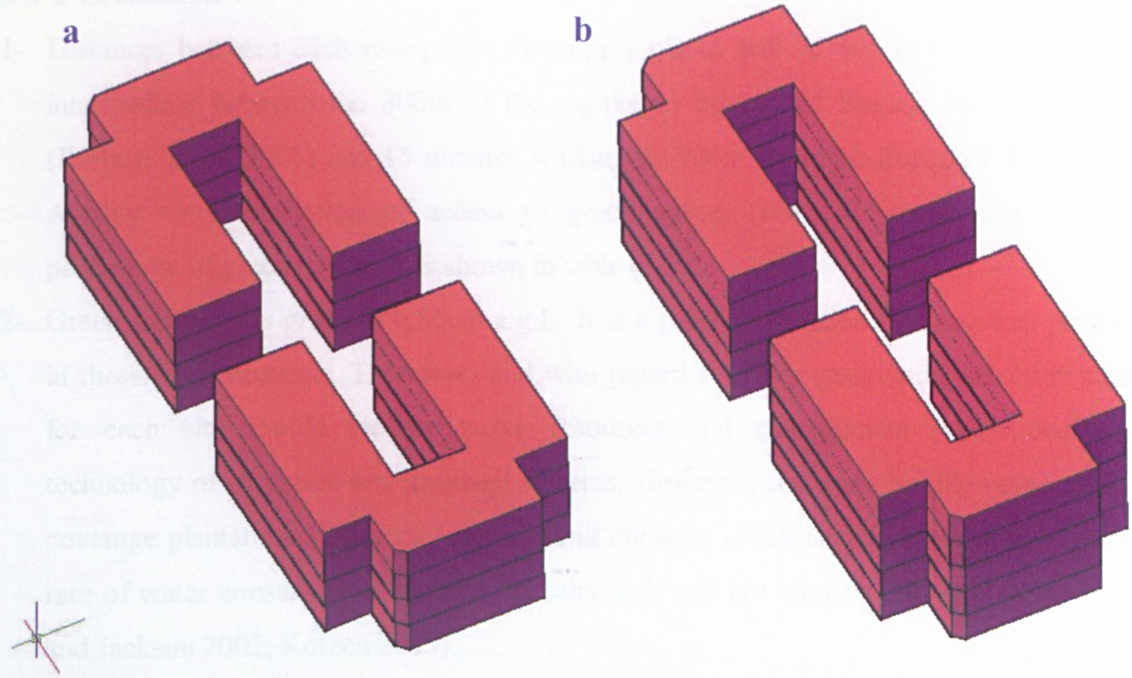


Figure (5-5/a, b): 3-D CAD plots for; a) to the left, is a typical clustered 4 floors housing used in C1DS1 and C2DS1. b) To the right is the typical 5 floors clustered mixed uses applied in extra sample of the URPLA model in section 5.5.3.

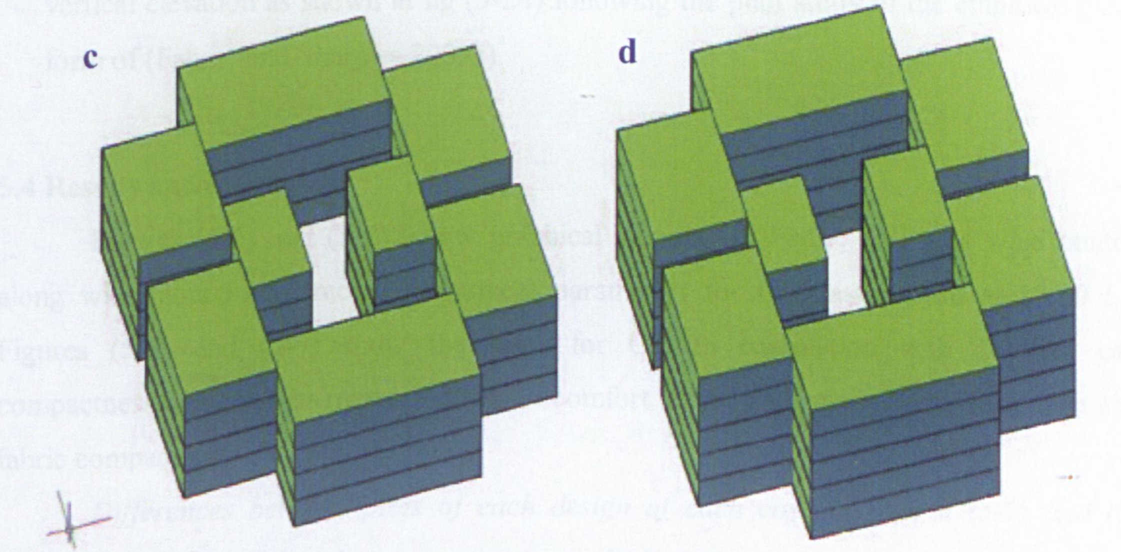


Figure (5-5/c, d): 3-D CAD plots for; c) to the left, is a typical 4 floors refined clustered housing used in C1DS2 and C2DS2. b) To the right is the typical 5 floors refined clustered mixed uses applied in extra sample of the URPLA model in section 5.5.3.

5-3-2 GreenSect.

1- Distances between each two public GreenSect places will be 600 metres on average as intermediate between the 300m of the regulatory agency of English Nature standards, (Barbosa et al. 2007) and 15 minutes walking or 900m from the European Environment Agency recommendation of access to green space, (Barbosa, et al., 2007). The percentage of green coverage is shown in table (5-5).
2- Green coverage is grass of 0.80cm a.g.l. It is a place to mention that research presented in thesis is theoretical. Therefore, and with regard to Cairo geography, selection studies for each site should include water resources and management which decide the technology of irrigation and drainage systems. However, there are a wide range of green coverage plantations that cope with the arid climates which is characterized with the low rate of water consumption, bearable to salty soils and hot climate (Snyman 1998; Schenk and Jackson 2002; Kotzen 2003).
3- Urban trees were arranged so that a completion for the UC spaces is achieved along with the sheltering effect which also decreases time of exposure to short-wave solar radiation. In addition, environmental stimulation and naturalness are introduced in terms the urban green scene percentage only as their thermal impacts can not be evaluated in ENVI-met. This is introduced as a trees green colour percentage of not less than 33% of any canyon's vertical elevation as shown in fig (3-24) following the pilot study of the empirical passive form of (Fahmy and Sharples 2009a).

5.4 Results and discussion

Figures (5-6) and (5-7), show graphical mapping of PMV, SVF and wind contours along with plots for extracted assessment parameters for C1 master plans at 13.00 LST. Figures (5-8) and (5-9) show the same for C2. In completion with different cases' compactness degrees that revealed different comfort levels, SVF maps can give an idea about fabric compactness.

Differences between plots of each design of each case in figures (5-7) and (5-9) indicate the effect of that design compactness which represents the urban fabric volume and population (Eq.8) in addition to vegetation effect. The information presented in figures (5-7) and (5-9) was plotted to represent a complete urban site climate rather than to measure or record to represent specific points even if the minimum and maximum of meteorological parameters were discarded as they will not give an accurate idea about the whole *neighbourhood climate so that a differentiation between cases won't take place. However, such minimum and maximum values can be interpreted from the corresponding maps.*

In general, the combined local climate conditions of low wind speeds with a high intensity solar access attributed to C1 physical form concluded high local average PMV values as shown in figure (5-7/e). The increased sheltering of C1DS1 and C1DS2 in terms of more compactness (1.169, 1.264) as shown in table (5-5) revealed considerable reductions in PMV until early evening. Another thermal performance appeared in C2, regardless the sheltering provided by BC2 compactness (2.027) and the less compactness of C2DS1 (1.310) and C2DS2 (1.366), it seems that the spatial structure, orientation and the more RH due to vegetation, equalled the effect of less sheltering of both C2DS1 and C2DS2 and hence a close averaged PMV values for all C2 design suggestions, fig (5-9/e). The following sections discuss these different aspects in details.

5.4.1 The Fifth Community

Basically, by increasing *Dc*, the PMV values showed reductions when compared with BC. As the solar altitude increases street canyons within each urban pattern is heated, reaching the maximum PMV at 13.00 for BC and DS1 (which are the same zoning). Close to sunset, and due to the availability of sensible heat release in the early evening, the comfort scale decreases significantly from 4.9 at 13.00LST to only 2.0 at 18.00LST by applying the DS1 plan which can not be considered an acceptable comfort level of coarse, but with regard to the day of the year in Cairo, it is acceptable. PMV has recorded reductions from BC to DS1 of about 0.1-0.7 due to the clustered form which is the only difference from the BC in addition to the increased *Dc* from 0.799 of BC1 to 1.169 of C1DS1.

As DS2 and DS3 are same zoning (master planning), their PMV curves showed the same trend of urban pattern and street canyon thermal behaviour but with a remarkable difference between BC and DS1. Their comfort peak was at 15.00 instead of 13.00, which is explained by the increased *Dc* that offered more direct radiation shelter as well as more trapped sensible heat emitted from the fabric walls and tiled floor. The evening behaviour is also different but this cannot be owed to *Dc* as the neighbourhood quarter's public green areas offers nocturnal cooling nodes. It can be owed to the increased number of dense trees used (LAI of 3) that have been used to provide more shelter. At the same time, however, it has increased the trapped long-wave radiation from the ground and near walls by the tree' canopies itself which is in good agreement with (Fahmy et al. 2010) who recorded a trapped heat with the same tree (LAI of 3) canopy. The different zoning, *D*c, number of trees and clusters aspect ratios with orientation moved the whole comfort trend as if the urban form acted as a massive thermal storage wall.

In comparison with BC, DS2 recorded PMV differences of about 1.7 at 6.00LST, crossing the BC curve at almost 14.20LST and recording increased difference from BC of about 0.6-1.4 PMV from the early evening until sunset. The local scale clustered form with dense tree arrangements delayed heating by day and cooling by night. It can be said that the whole urban passive cooling system as configured turned the neighbourhood form into an *urban thermal mass* named as *Fahmy thermal mass* that shifted *T*mrt and PMV curves from the BC values with *urban time lag* of 2h for DS2 and DS3 peaks from BC1 and DS1 peaks. The use of less walls albedo values in DS3 (0.15) resulted in less diffuse short-wave radiation introduced to the fabric concluding less comfort levels by day in comparison to DS2 which is same land use and urban planning parameters. As the solar altitude decreases the albedo effect on reducing heat gain is minimized, which can be noticed from the close comfort levels of DS2 and DS3 from 15.00LSt until sunset.

The ambient conditions of *T*a, RH and V are all different from those measured at Cairo Airport, not only for the limitations discussed before, but also due the urban form effect in comparison to open places. *T*a records of DS1 are less than BC records with maxima of 2°C before noon due to the whole urban heat gain by increased *D*c and then close to each other, starting from 13.00LST, whereas DS2 and DS3 *T*a trends are almost the same. In other words, all street canyon aspect ratios have increased in DS1.

The mean wind speeds of DS1 are less all the time than the corresponding BC values due to the increased roughness of DS1. In DS2 and 3 the canyons tunnelling effects due to orientating the street canyons to capture north cool breezes increased the mean V of all site for both cases from BC by about 0.2 m/s and about 0.4m/s from DS. The small increase of DS1 is owed to its same zoning of BC1 so that wind is scattered and didn't help releasing heat stored in canyons, fig (5-6/i, j, k). Moreover, the UCL heights of all BC1, C1DS1 and C1DS2 in terms of the average no. of floors for all of them are close of 3.17, 3.91, and 4.07 respectively as shown in table (5-5). The considerable local averaged wind speed difference, fig (5-7/c) and the wind tunnelling effect concluded as shown in fig (5-6/j, k) guided towards extracting a windward-leeward sectional illustration to investigate the effect of the high buildings placed following (Priyadarsini et al. 2008) as discussed in section 5.3.1. Fig (5-6/l) show a windward-leeward section through the high rise buildings of 7 floors placed to increase ISL blending with the UCL wind at pedestrian level which revealed a single vortex in the canyon and helped an overall less discomfort levels at peak time of C1DS2 with reference to C1DS1.

RH has increased as expected due to the increased green coverage and urban trees which also affect the amount of trapped heat $Lv\downarrow$ and in turn helped the shifting appeared in the PMV records towards the evening time. $Lv\downarrow$ showed a large increase of about 30 W/m^2 for all simulation time for DS1 and about 50 W/m^2 for both DS2 and DS3. *S*wdir is a maximum for the whole site at 9-11:00LST due to the orientation of the form and then starts to decrease with time until sunset.

*S*wdir of C1DS1 has been decreased by about 120 W/m^2 from BC1 at all time until before sunset owed to the increase in *D*c, i.e. provide shelter by controlling access and minimizing time and area of exposure to direct radiation, whereas C1DS2 showed reduction ranged from 400 at early simulated time then crosses BC1 curve at around 11.30 am after which the compactness didn't help as the canyons were oriented towards the sun, fig (5-7/f). This illustrates the benefit gained from clustering the urban fabric and sensitive plantation of trees. Moreover, $Lw\leftrightarrow$ is shifted up the curve by about 14 W/m^2 for DS1 from BC due to the increase in *D*c, which fabric emitted more long-wave radiation which in combination of trees trapped heat caused the urban thermal mass in terms of the PMV shift. Both DS2 and 3 are almost identical in their direct gain whereas their *S*wdif differs by about 20-60 W/m^2 in all simulation runs due to the different albedo values.

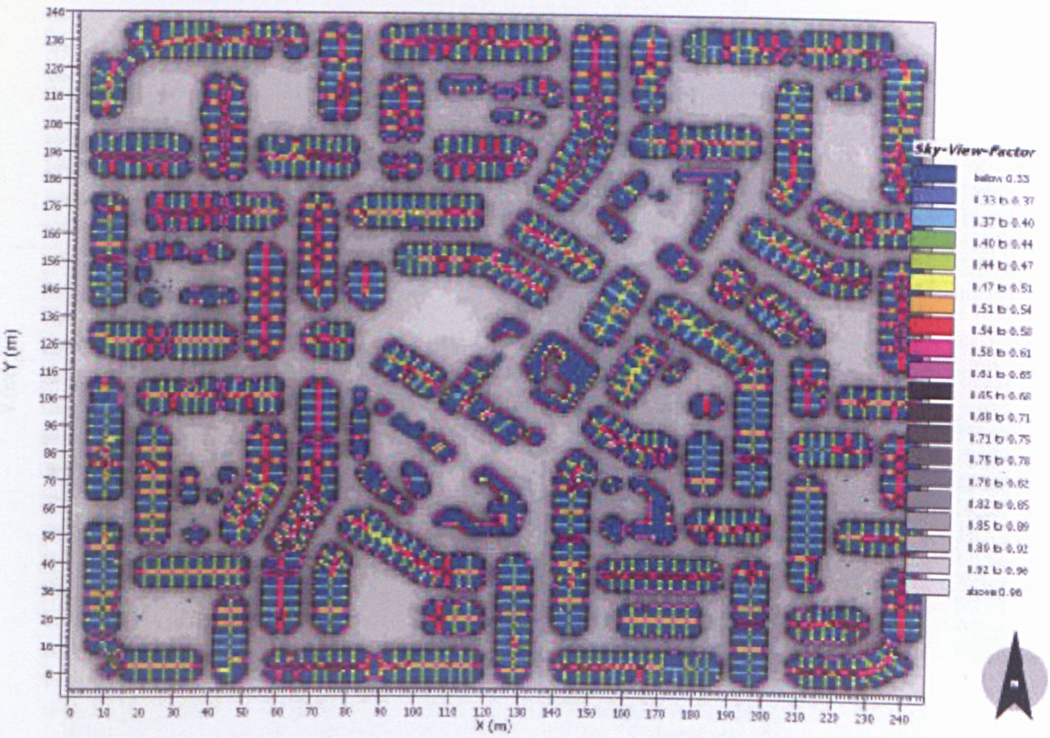


Figure (5-6/a): SVF mapping of BC1.

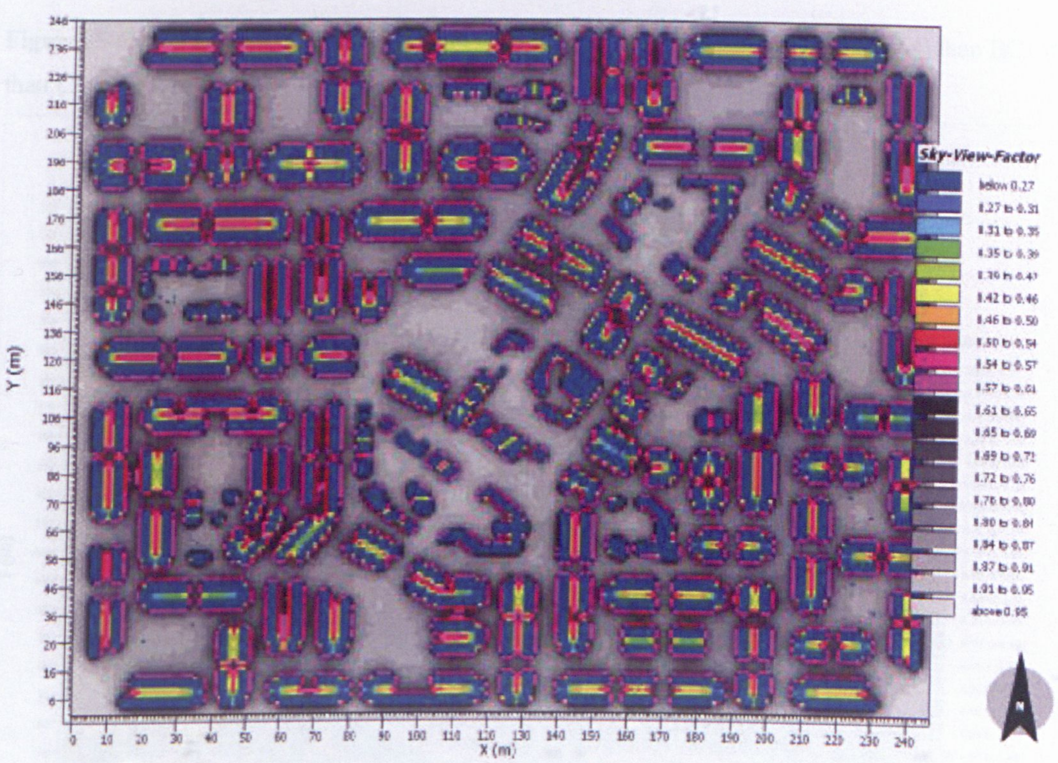


Figure (5-6/b): SVF mapping of C1DS1.

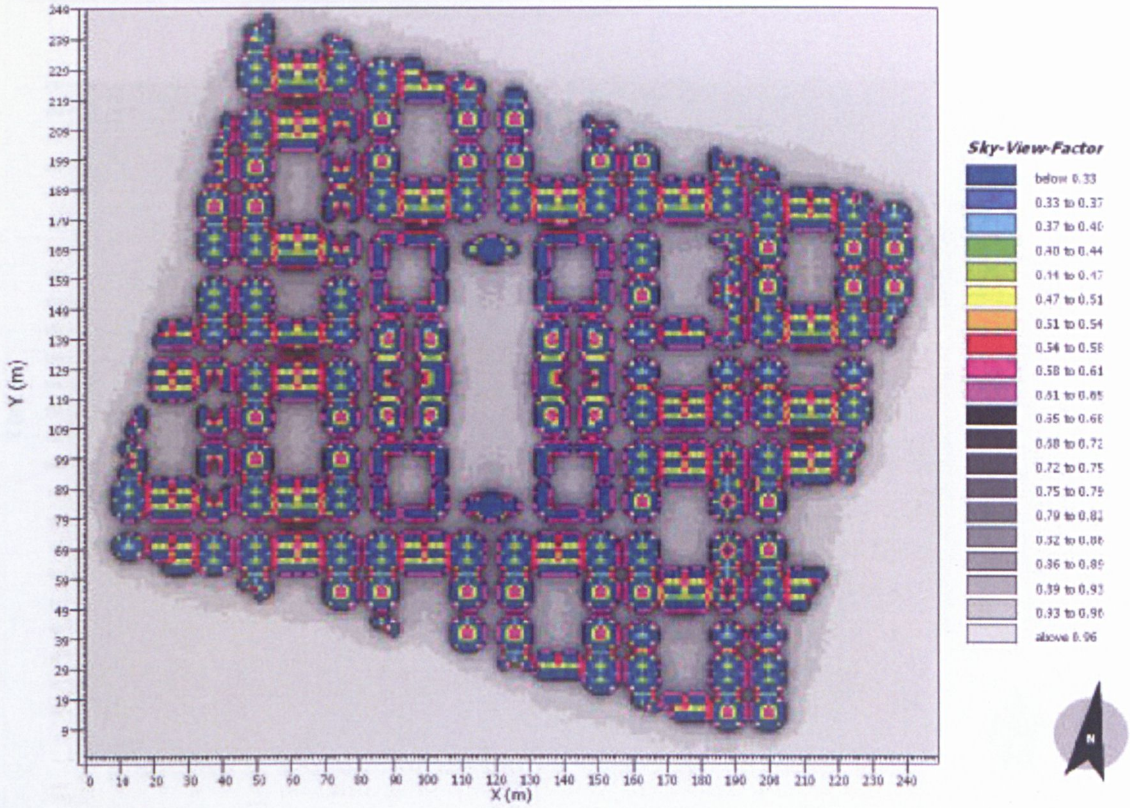


Figure (5-6/c): SVF mapping of C1DS2 and C1DS3 indicates more compactness (1.264) than BC1 (0.799) and than C1DS1 (1.169).

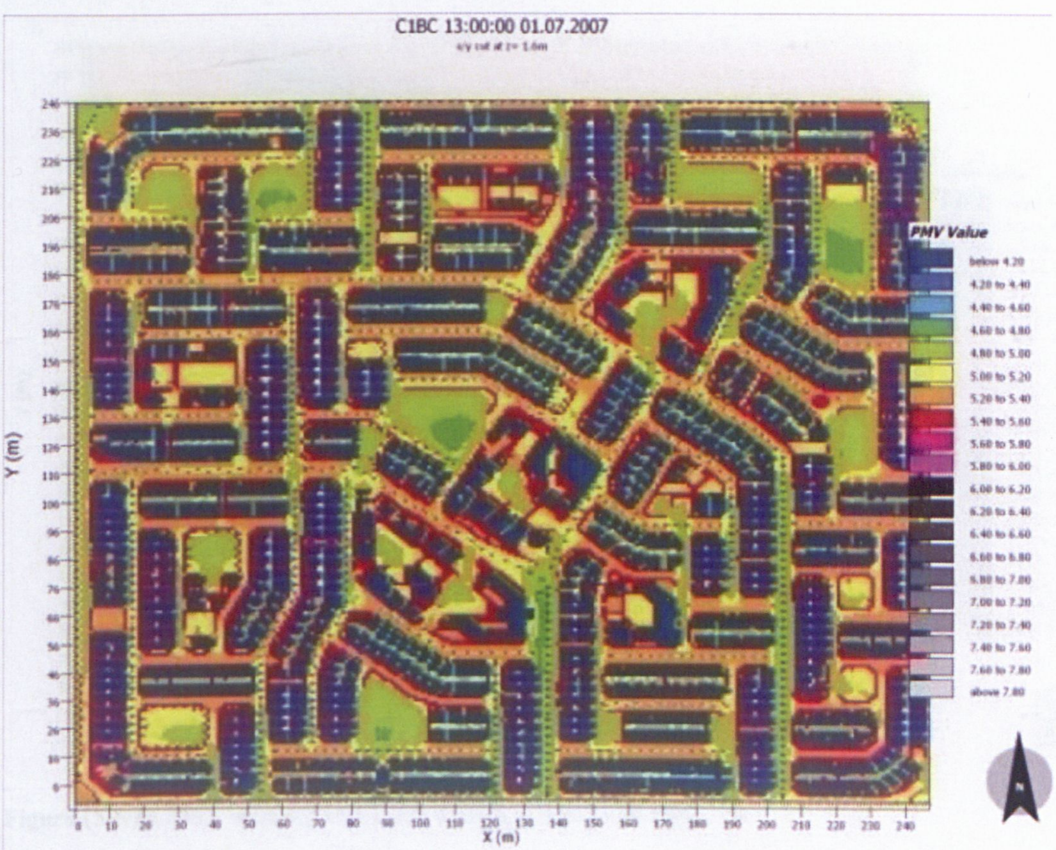


Figure (5-6/d): PMV mapping of BC1 1.6m a. g. l.at 13.00 LST.

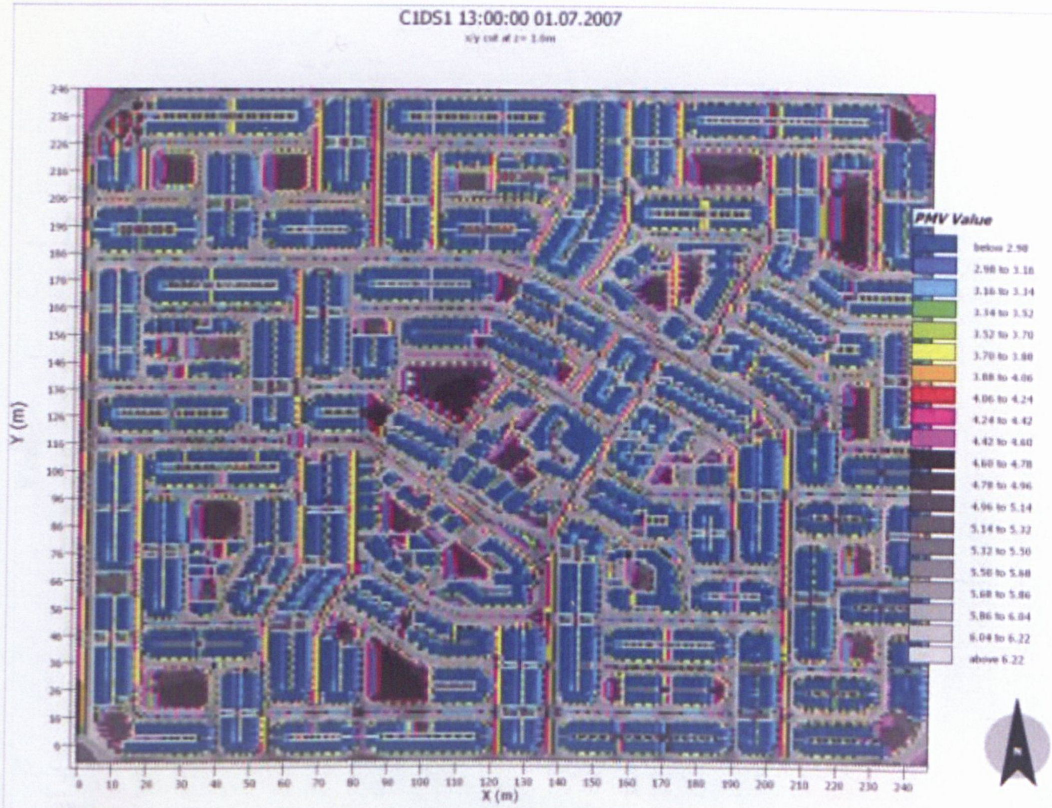


Figure (5-6/e): PMV mapping of C1DS1 1.6m a. g. l.at 13.00 LST.

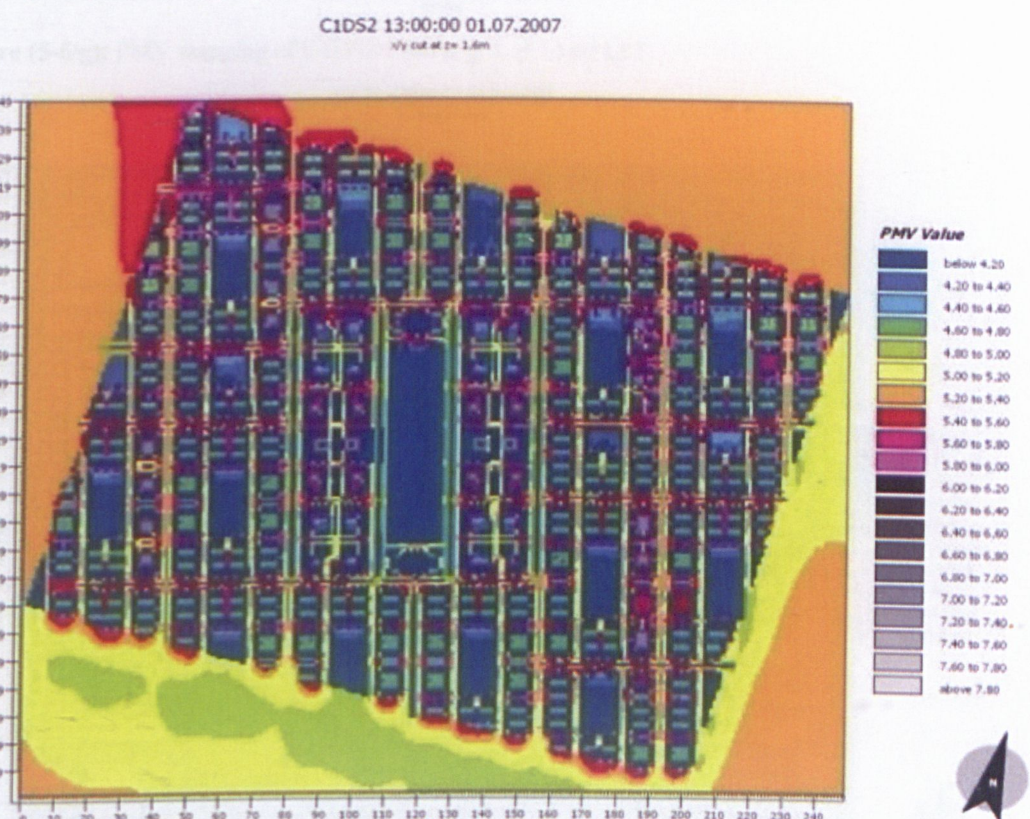


Figure (5-6/f): PMV mapping of C1DS2 1.6m a. g. l.at 13.00 LST.

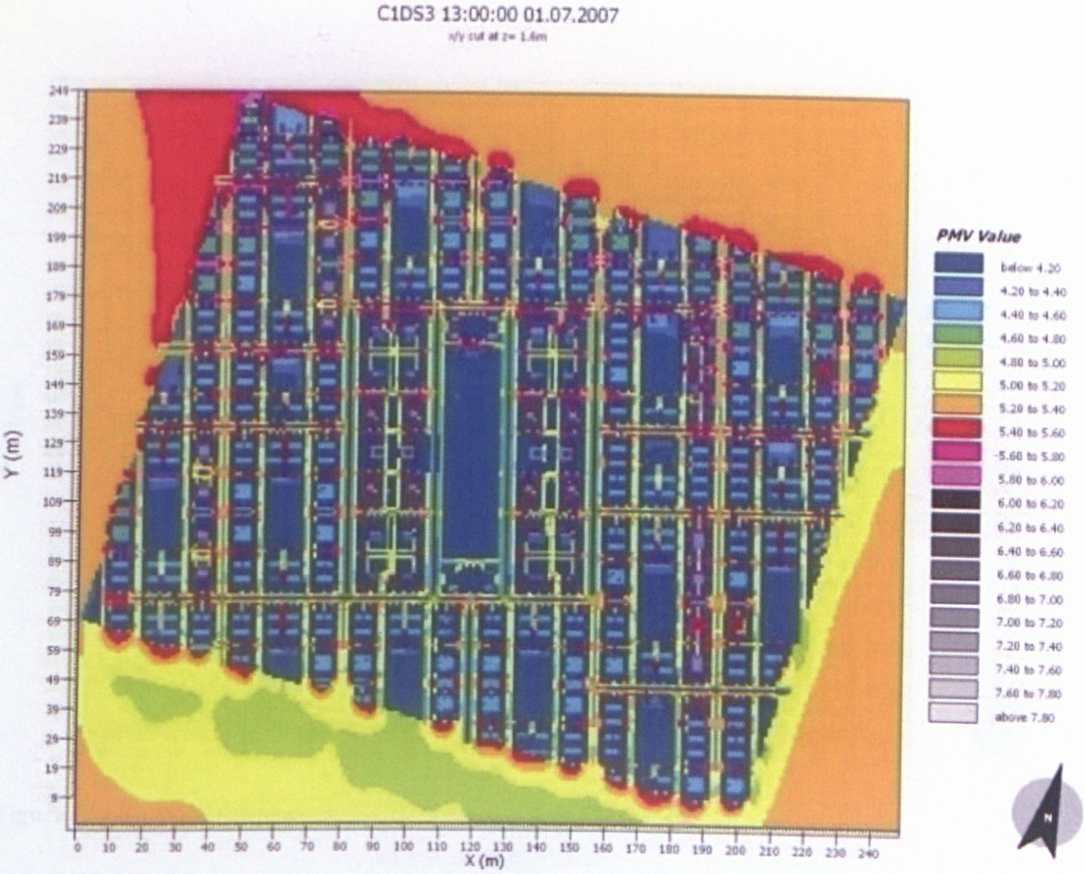


Figure (5-6/g): PMV mapping of C1DS3 1.6m a. g. l. at 13.00 LST.

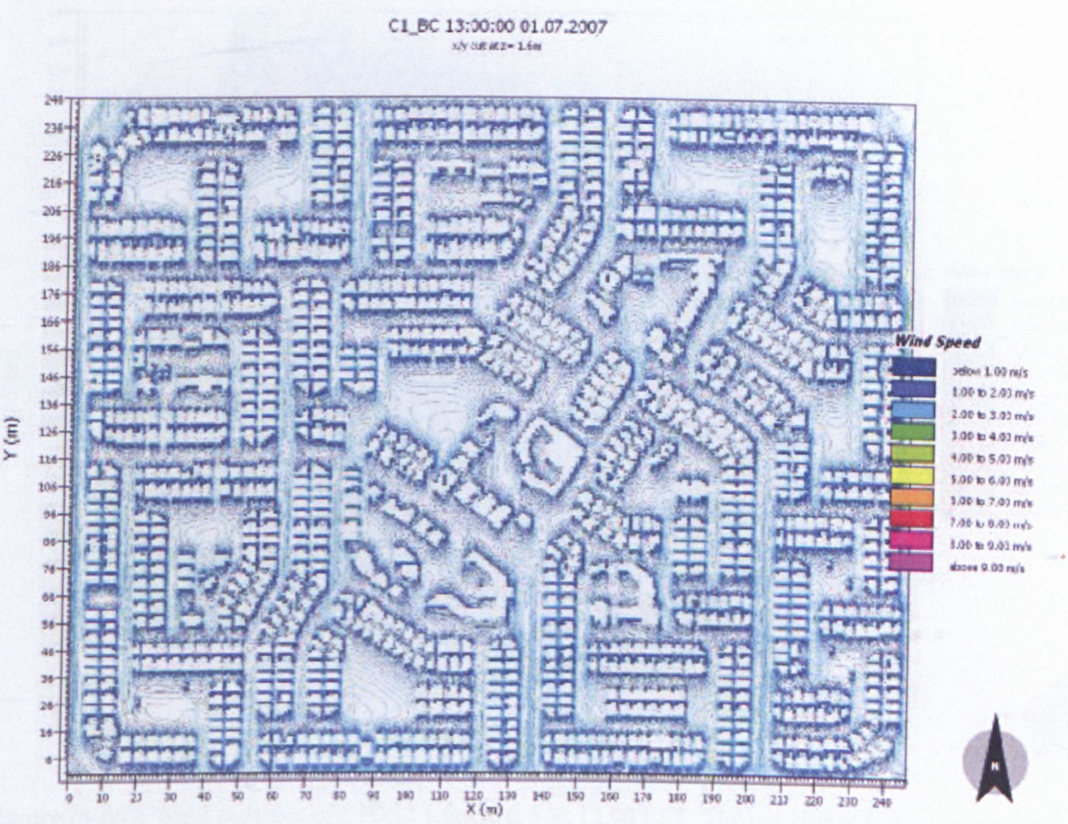


Figure (5-6/h): Wind contours of BC1 1.6m a. g. l. at 13.00 LST.

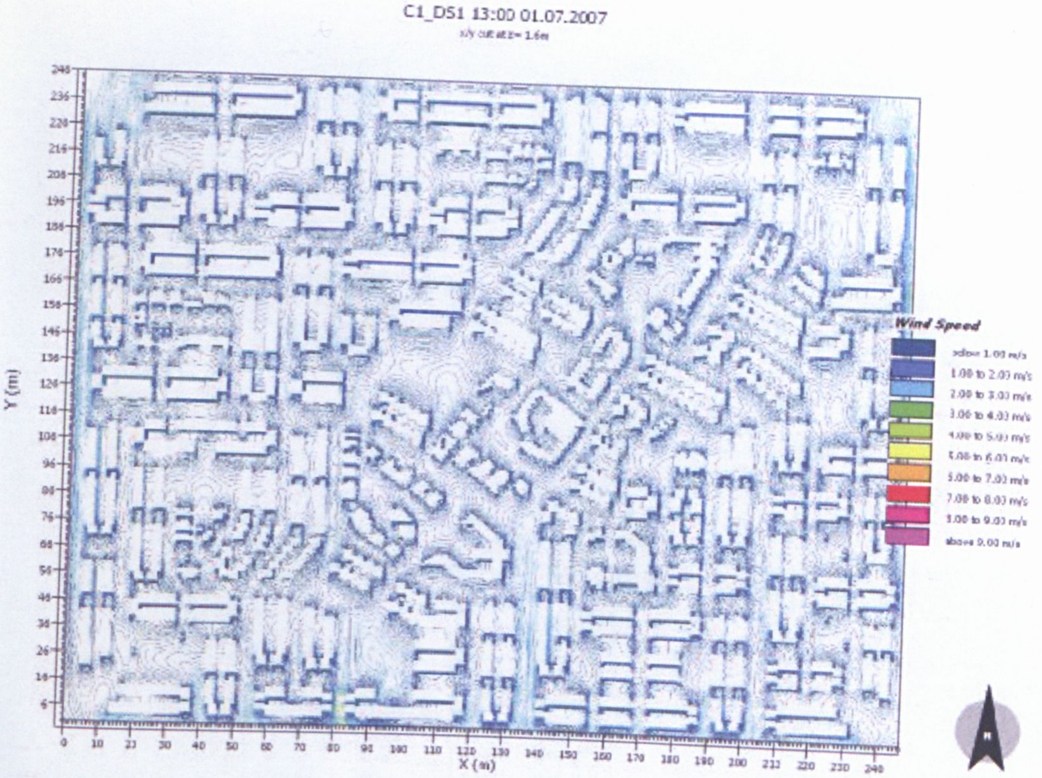


Figure (5-6/i): Wind contours of C1DS1 1.6m a. g. l. at 13.00 LST.

Figure (5-6/j): Wind contours of C1DS2 1.6m a. g. l. at 13.00 LST. The red ellipse is the capture illustration below whereas the section line and the red circle at the left is shown in fig (5-6/l).

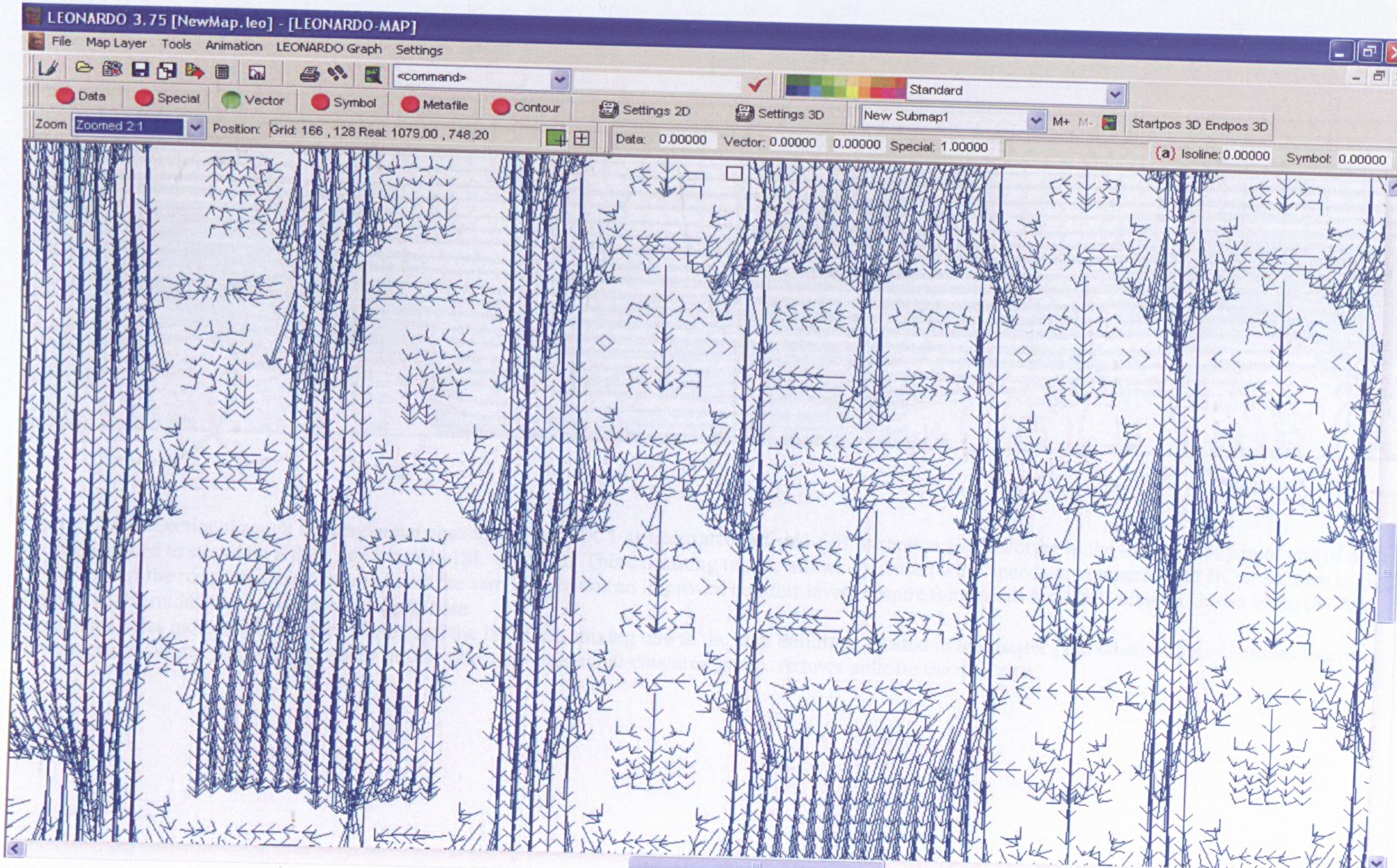


Figure (5-6/k): A flow capture from fig (5-6/j) showing the wind tunnelling effect in the canyons and clusters turbulences of C1DS2, 1.6m a.g.l. at 13.00 LST.

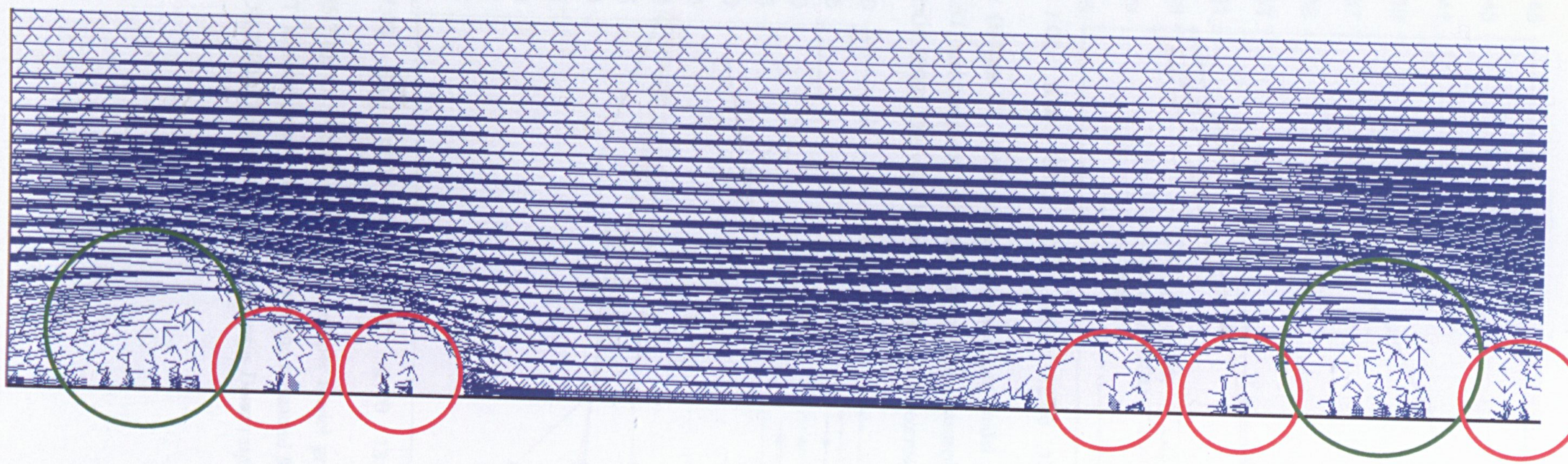


Figure (5-6/l): Section through the residential clustered group of C1 as illustrated in fig (5-6/j), it show a single vortex in the leeward canyon of one of high buildings placed to stimulate a flow mix between ISL and UCL. This skimming regime allows increased wind speeds in comparison to BC are shown in fig (5-7/c) even if the roughness heights are almost the same and hence an improved comfort levels despite the overall hot PMV scale as shown in fig (5-7/e).
The area at the middle is the clustered group garden.
The green circles indicate the leeward vortex and the ISL-UCL mixing due to the high buildings located in the master plan whereas the red circles indicate vortices due to the canyons aspect rations of 0.6 within the residential clustered group. Arrows indicate the direction.

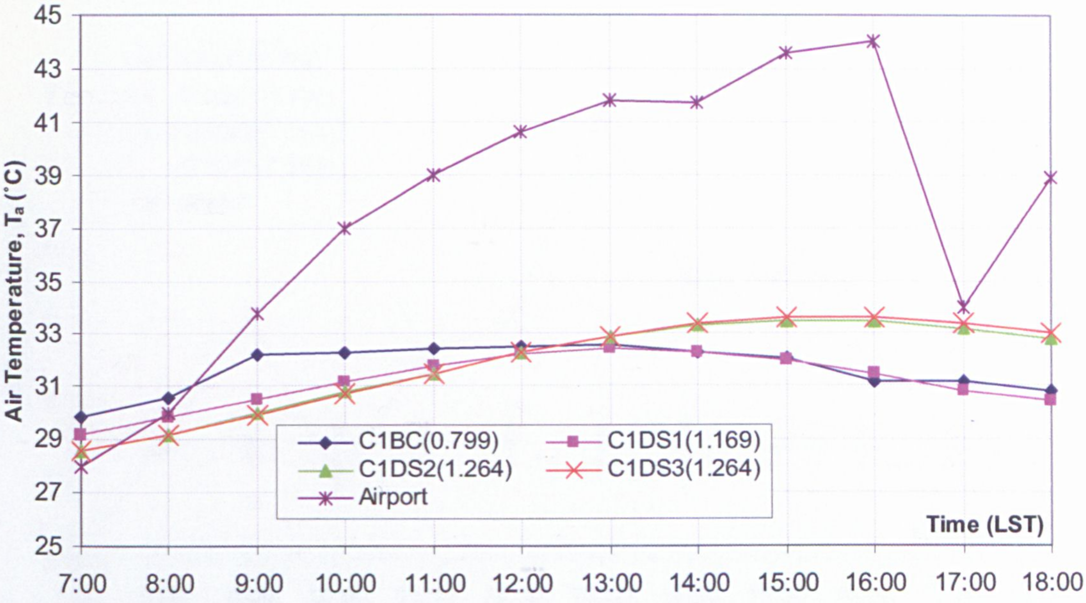


Figure (5-7/a): C1 output means calculated per model grid number using PolygonPlus for T_a from 7:00-18:00LST, and compared with its corresponding measured T_a at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is D_c corresponding to each master plan.

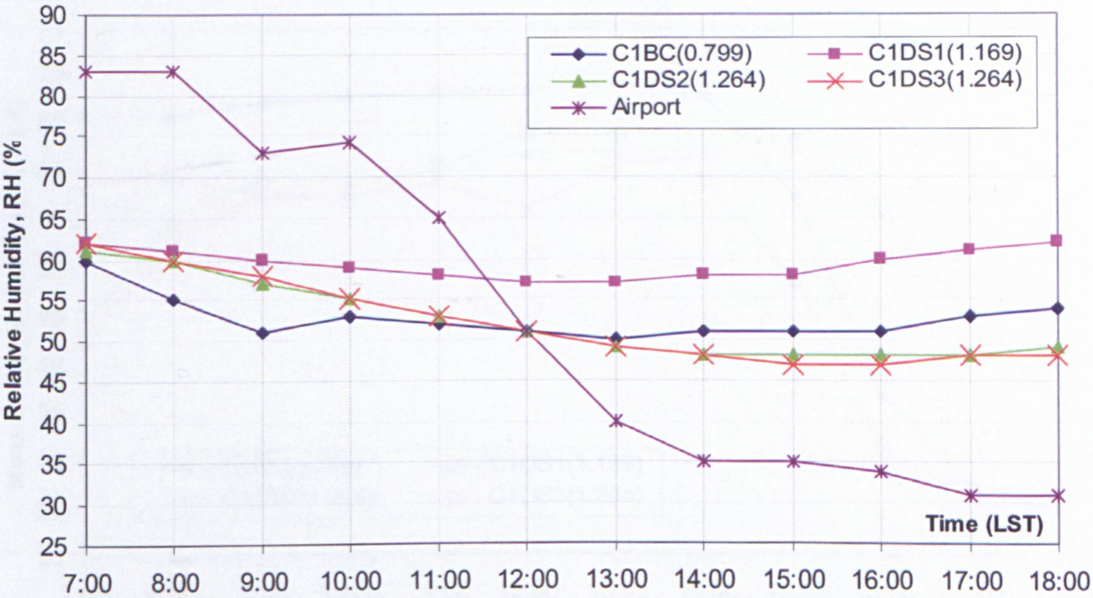


Figure (5-7/b): C1 output means calculated per model grid number using PolygonPlus for RH from 7:00-18:00LST, and compared with its corresponding measured RH at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is D_c corresponding to each master plan.

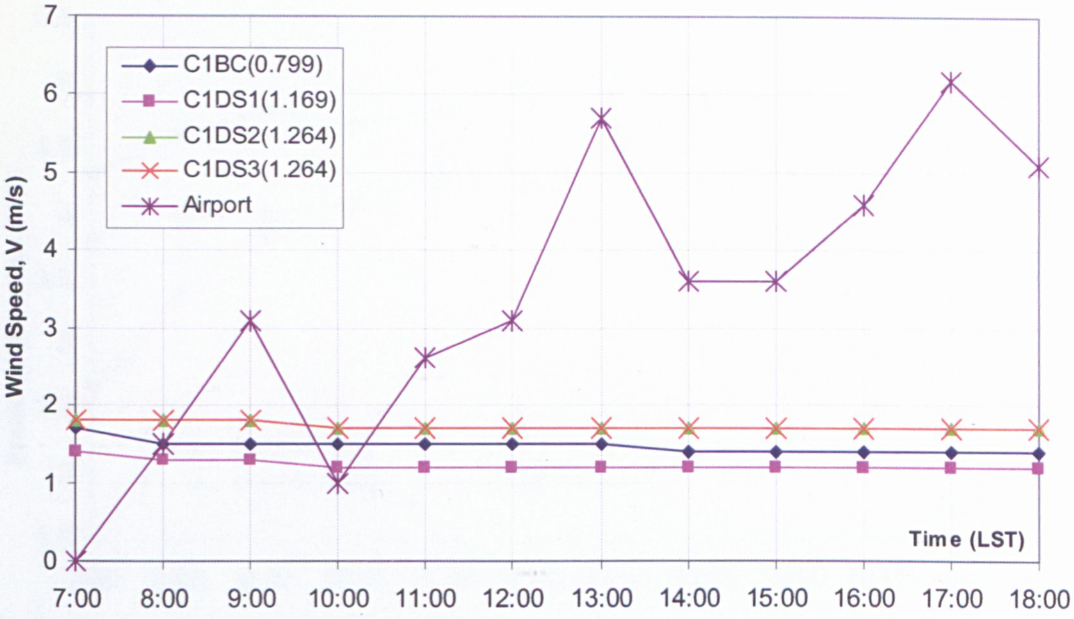


Figure (5-7/c): C1 output means calculated per model grid number using PolygonPlus for V from 7:00-18:00LST, and compared with its corresponding measured V at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***Dc*** corresponding to each master plan.

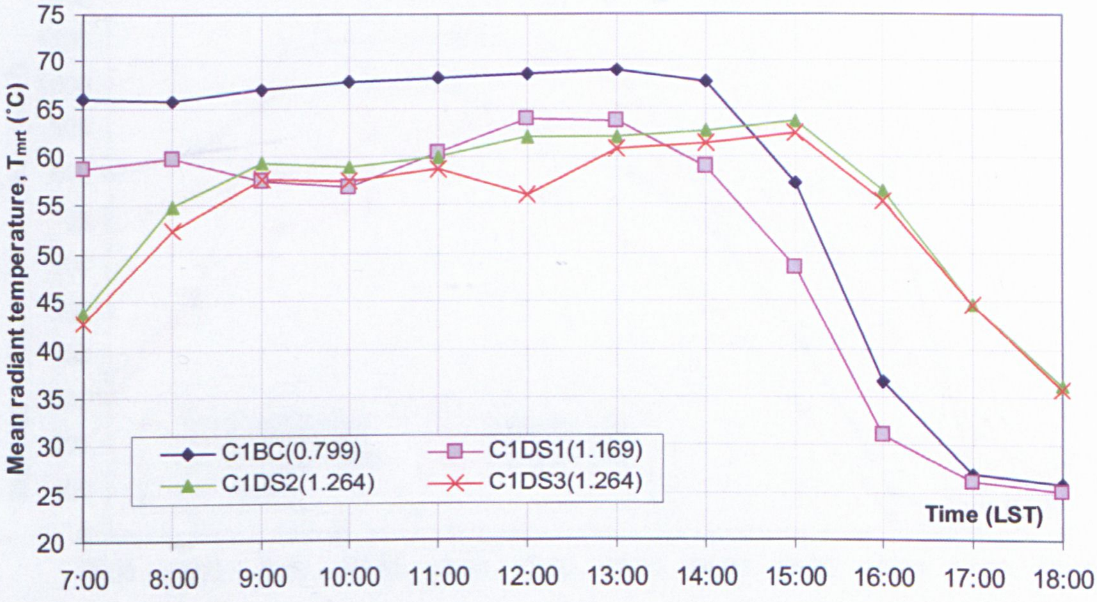


Figure (5-7/d): C1 output means calculated per model grid number using PolygonPlus for T_{mrt} from 7:00-18:00LST showing an urban thermal mass effect, named as Fahmy thermal mass with urban time lag of 2h. The value between brackets is ***Dc*** corresponding to each master plan.

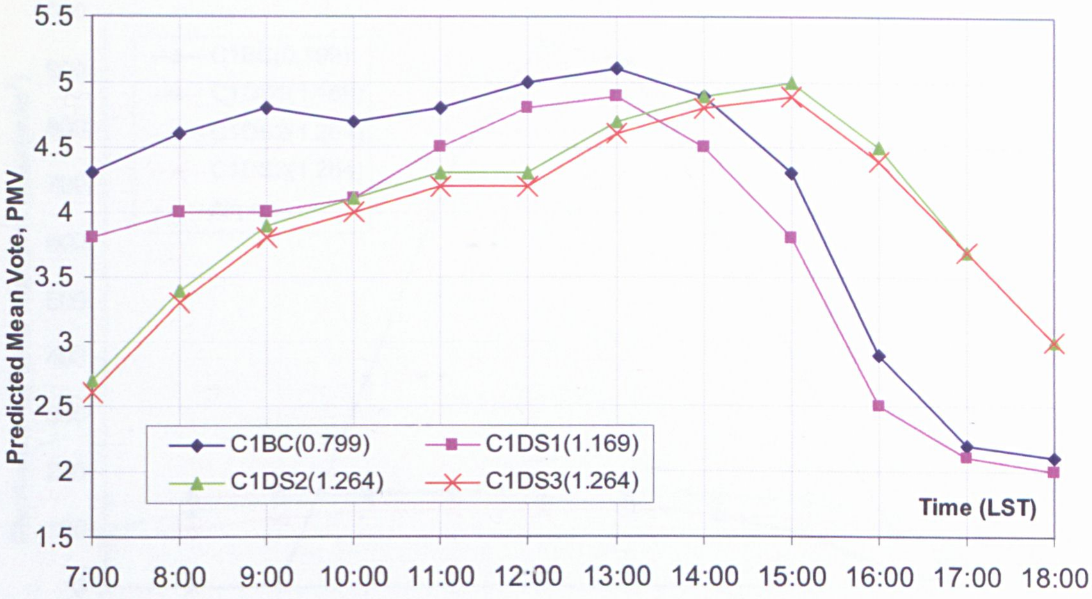


Figure (5-7/e): C1 output means calculated per model grid number using PolygonPlus, PMV Comfort levels showing an urban thermal mass effect, named as Fahmy thermal mass with urban time lag of 2h. The value between brackets is ***D*c** corresponding to each master plan.

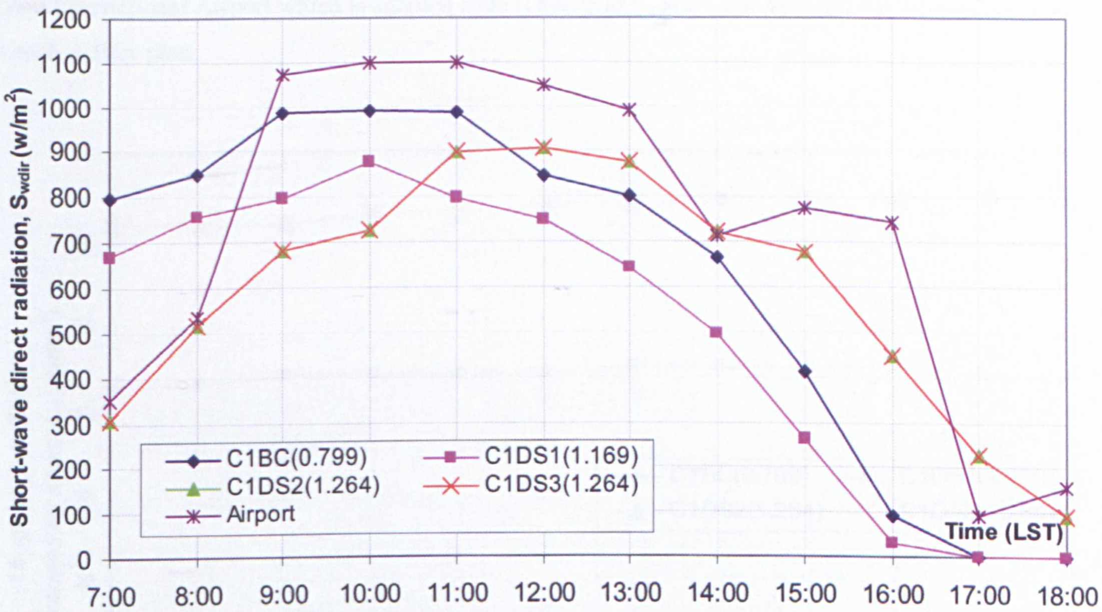


Figure (5-7/f): C1 output means calculated per model grid number using PolygonPlus for Short-wave direct radiation from 7:00-18:00LST, and compared with its corresponding measured Short-wave direct radiation at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***D*c** corresponding to each master plan.

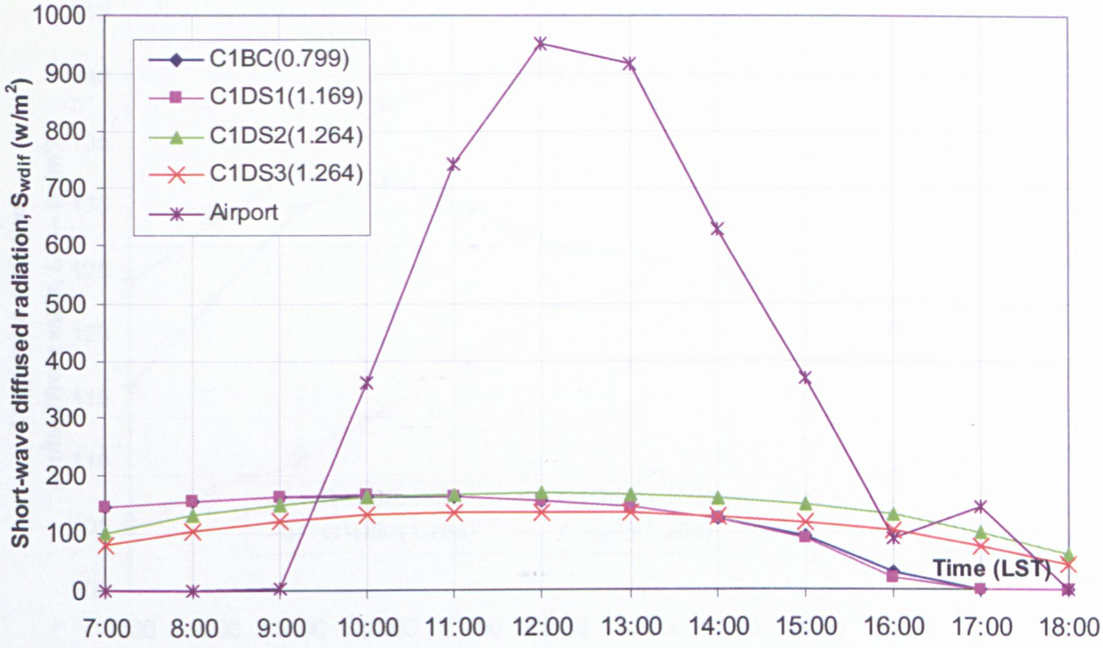


Figure (5-7/g): C1 output means calculated per model grid number using PolygonPlus for Short-wave diffuse radiation from 7:00-18:00LST, and compared with its corresponding measured Short-wave diffuse radiation at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is D_c corresponding to each master plan.

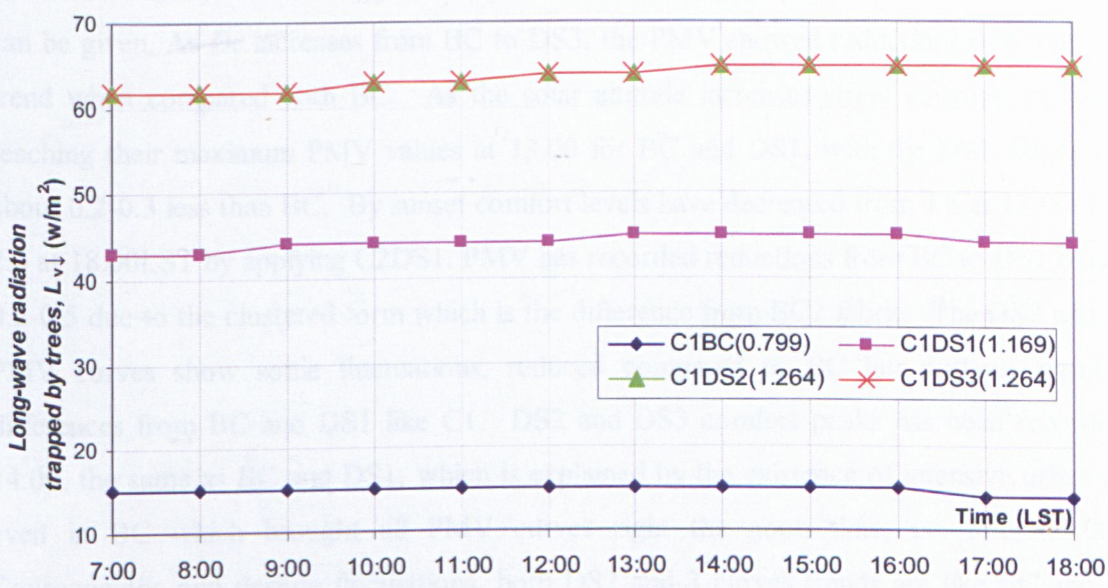


Figure (5-7/h): C1 output means calculated per model grid number using PolygonPlus, Long-wave trapped radiation by vegetation. The value between brackets is D_c corresponding to each master plan.

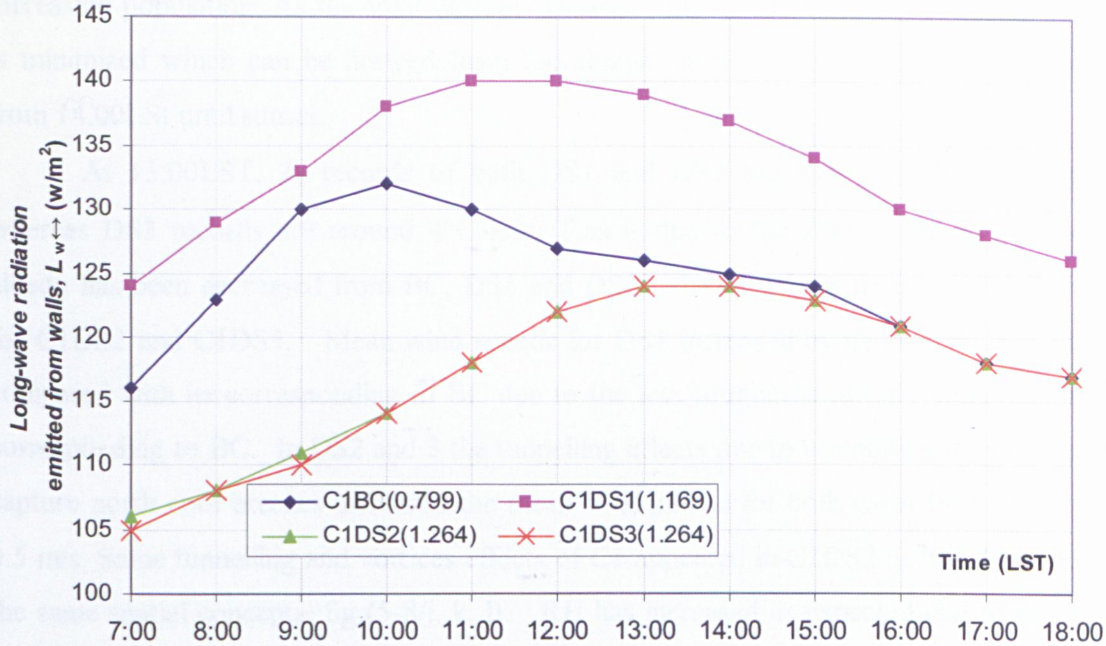


Figure (5-7/i): C1 output means calculated per model grid number using PolygonPlus, Long-wave emitted radiation from fabric. The value between brackets is ***Dc*** corresponding to each master plan.

5.4.2 Misr Al-Gadida

In this case study the same explanations for the whole urban pattern's thermal performance can be given. As *Dc* increases from BC to DS3, the PMV showed reductions over the whole trend when compared with BC. As the solar altitude increases street canyons are heated, reaching their maximum PMV values at 13.00 for BC and DS1, with the DS1 values being about 0.2-0.3 less than BC. By sunset comfort levels have decreased from 4.6 at 13.00LST to 2.6 at 18.00LST by applying C2DS1. PMV has recorded reductions from BC to DS1 of about 0.2-0.5 due to the clustered form which is the difference from BC2 fabric. The DS2 and DS3 PMV curves show some fluctuations, reduced compared to BC but without significant differences from BC and DS1 like C1. DS2 and DS3 comfort peaks has been recorded at 14.00, the same as BC and DS1, which is explained by the existence of intensive urban trees even in BC which brought all PMV curves right the noon time, i.e. after 13.00pm. Consequently, and despite fluctuations, both DS2 and 3 curves trends are like BC and DS1 but with minor differences. This is regardless the increased number of dense trees (LAI of 3) that have been used to provide more shelter, because the different zoning revealed less population and in turn less *Dc* of 1.366 for C2DS2 rather than 2.027 of BC2 which did not show the same shift as appeared in C1 even to the left side of the curve. A solution might exist in a mixed uses to allow more increase in aspect ratios, i.e. no. of floors without increasing population. As the solar altitude decreases the albedo effect on reducing heat gain is minimized which can be noticed from the almost close comfort levels of DS2 and DS3 from 14.00LSt until sunset.

At 13:00LST, *Ta* records of both DS1 and DS2 are less than BC by about 3°C whereas DS3 records are around 4°C less. This is due to the albedo, but in C1 walls the albedo has been decreased from BC, DS1 and DS2, which explains the matching *Ta* records for C1DS2 and C1DS3. Mean wind speeds for DS1 increased by about 0.3m/s in all times compared with its corresponding of BC due to the less roughness of DS1 compared with its corresponding to BC. In DS2 and 3 the tunnelling effects due to orientating street canyons to capture north cool breezes increased the mean V of all site for both cases from BC by about 0.5 m/s. Same tunnelling and vortices effects of C1 appeared in C2DS2 as it is designed using the same spatial concepts, fig (5-8/j, k, l). RH has increased as expected due to more green coverage and urban trees, the effect of which also appeared in the amount of trapped heat $Lv\downarrow$, the same as in C1 but with less difference from BC2. It showed an increase of about 10 W/m^2 for all simulation times for DS1 and about 35 W/m^2 for DS2 and DS3 due to the small difference of vegetation environment of C2 compared with its corresponding value in C1. $Lw_{\leftrightarrow}$ is shifted down by about 65 W/m^2 for DS1 from BC due to the decrease of the fabric volume which, in turn, is due to the lower *Dc*. The $Lw_{\leftrightarrow}$ decrease is minimized in DS2 and DS3 which are of same zoning and form. *Swdir* is a maxima for the whole site at 12:00LST and all DS1, 2 and 3 are less than measured at Cairo Airport (same as C1) with about 150 W/m^2 due to the orientation, clustering the urban fabric and sensitive plantation of trees. Both of DS2 and 3 are almost identical in direct gain whereas their *Swdif* matches BC and DS1 because the existence of trees in all situations and the same wall albedo. The biggest albedo difference in C2 has been made for the pavement to be 0.67 instead of 0.4 in BC, DS1 and DS2. This explains why the *Tmrt* of DS3 is greater than for the BC by about 2°C, which agrees with the concept of cool surfaces. A cool surface with a high albedo value reflects more radiation and in turn decreases the surface temperature resulting in less heat being transferred indoors. Overall, the less population clustered form used for Misr Al-Gadida has improved the local conditions as well as comfort levels only in comparison with BC2 with the help of the increased wind access, but the passive design used in C2DS2 didn't differentiate much from C2DS1 as both of them showed more solar access compared with BC2. Consequently, an attention should be given to using cool materials on large scale as they increase outdoor environment radiation interactions.

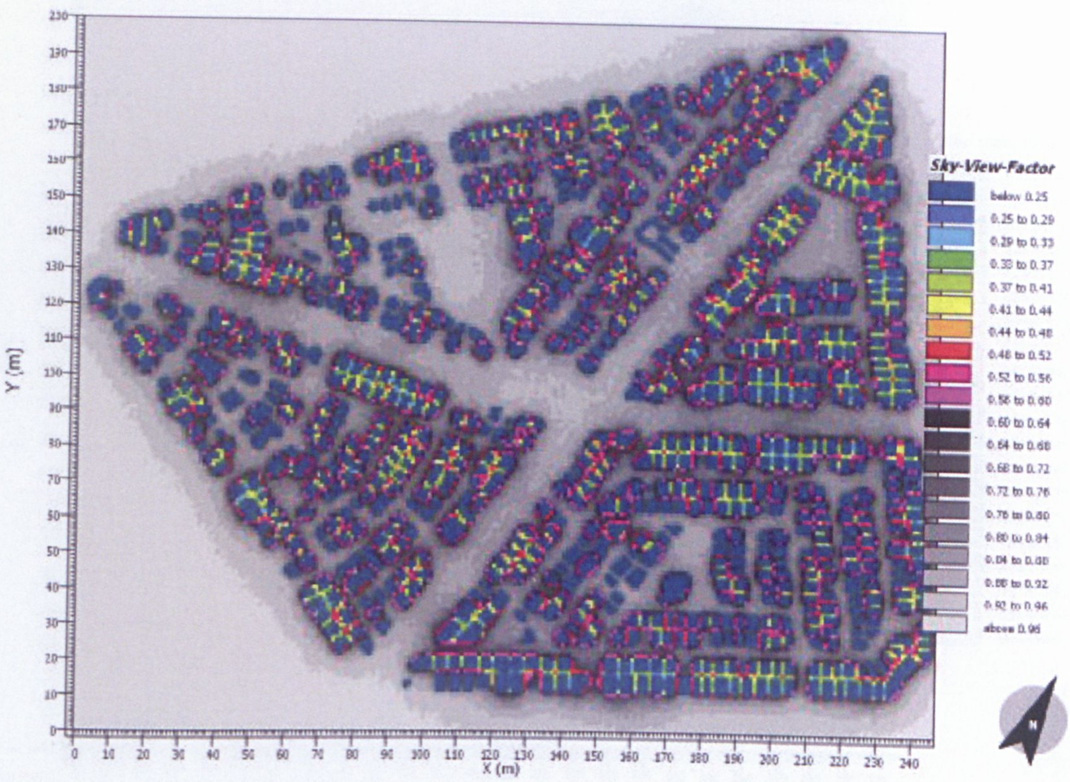


Figure (5-8/a): SVF mapping of BC1.

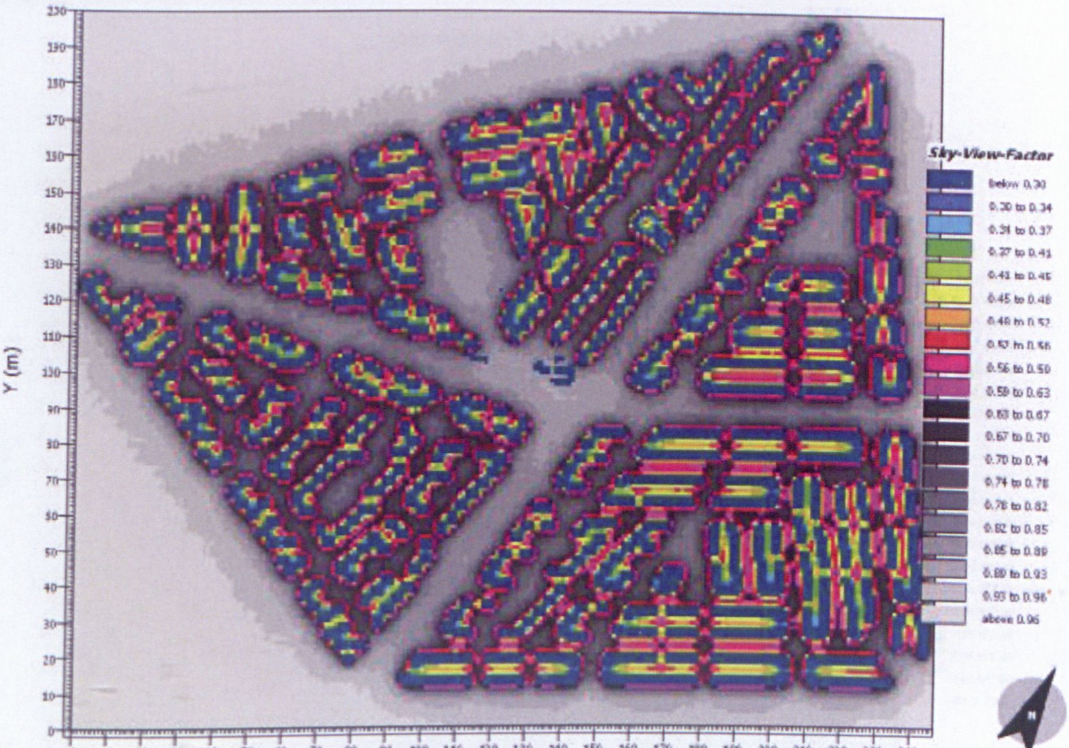


Figure (5-8/b): SVF mapping of C2DS1.

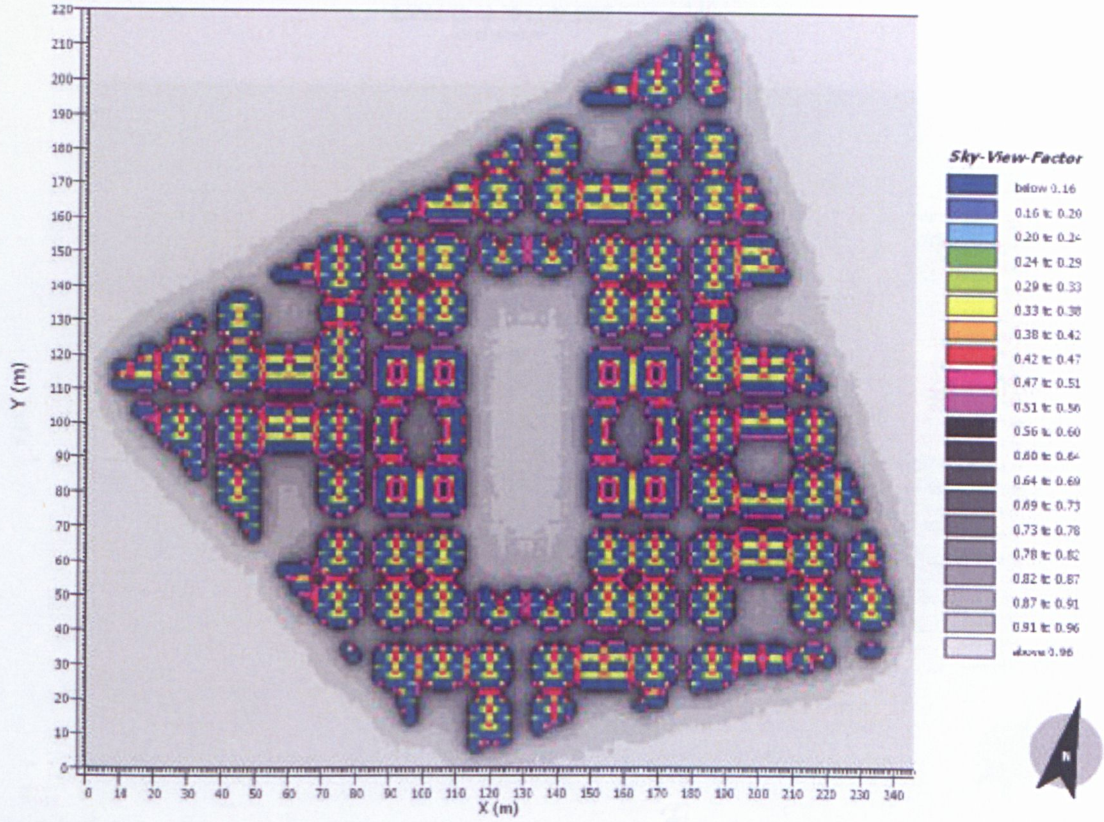


Figure (5-8/c): SVF mapping of C2DS2 and C2DS3 indicates less compactness (1.366) than BC2 (2.027) and slightly more than C2DS1 (1.310).

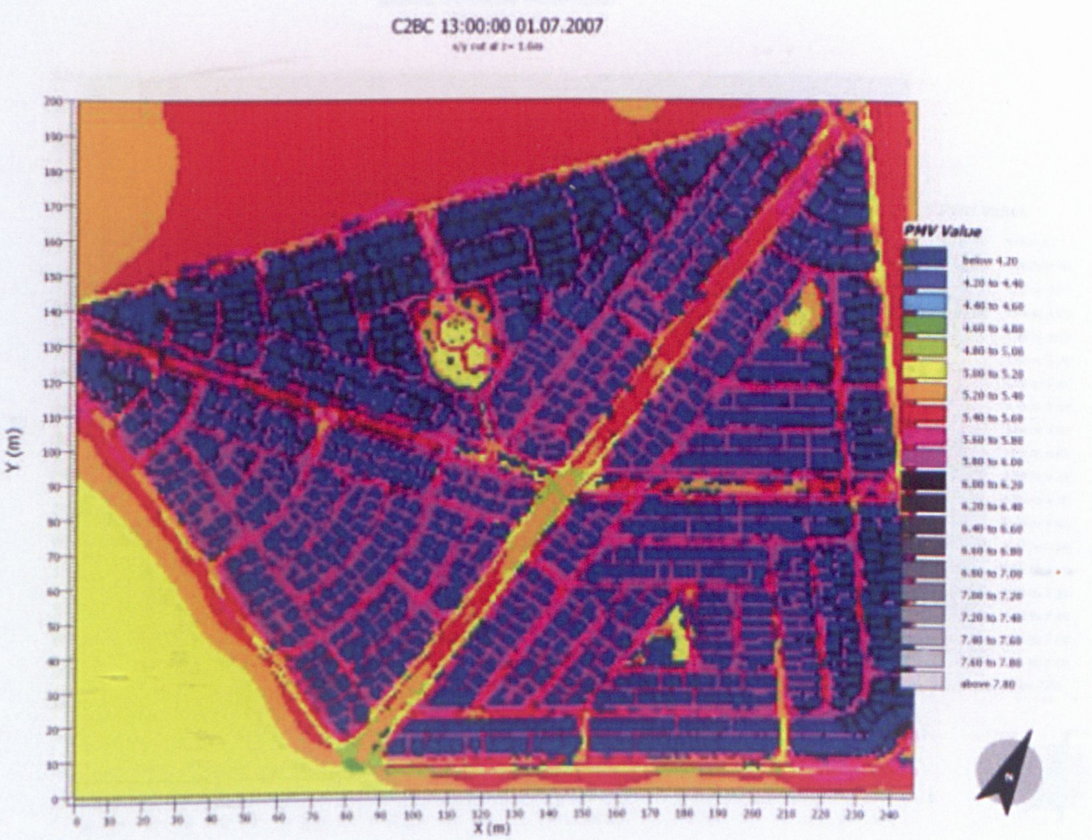


Figure (5-8/d): PMV mapping of BC1 1.6m a. g. l. at 13.00 LST.

Figure (5-8/e): PMV mapping of C2DS1 1.6m a. g. l. at 13.00 LST.

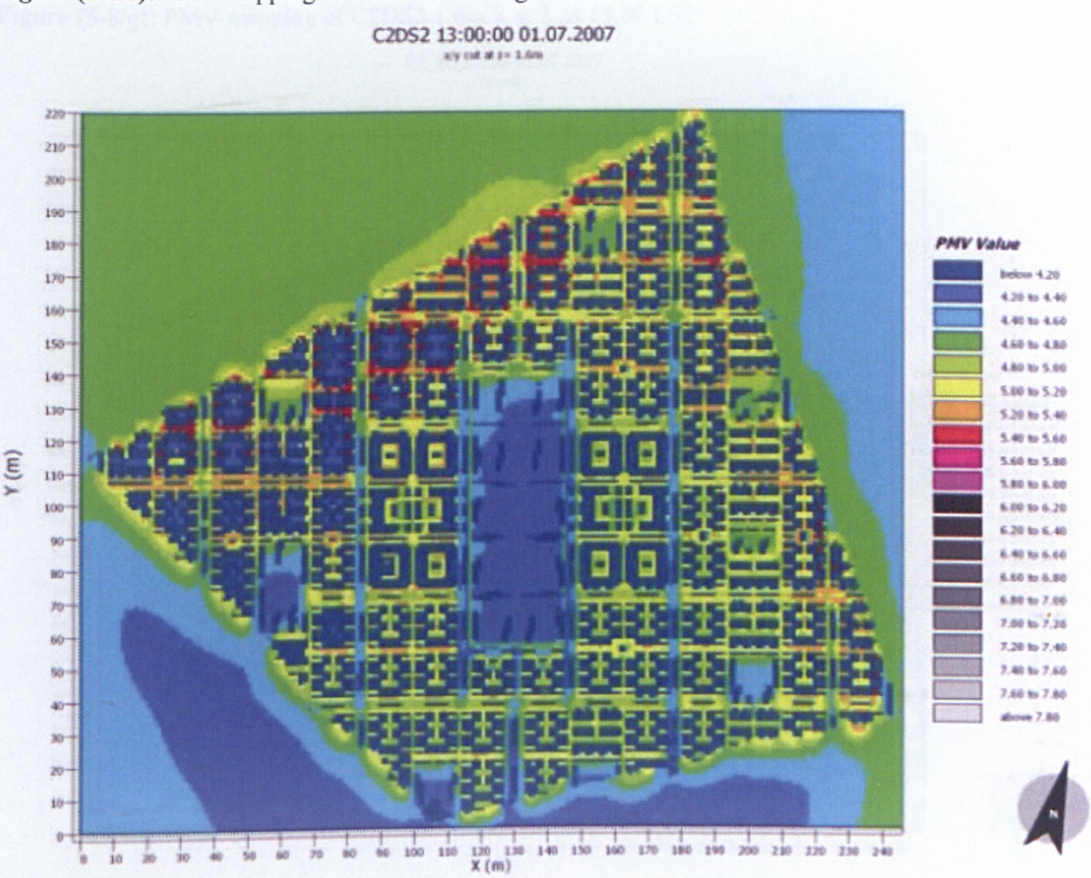


Figure (5-8/f): PMV mapping of C2DS2 1.6m a. g. l. at 13.00 LST.

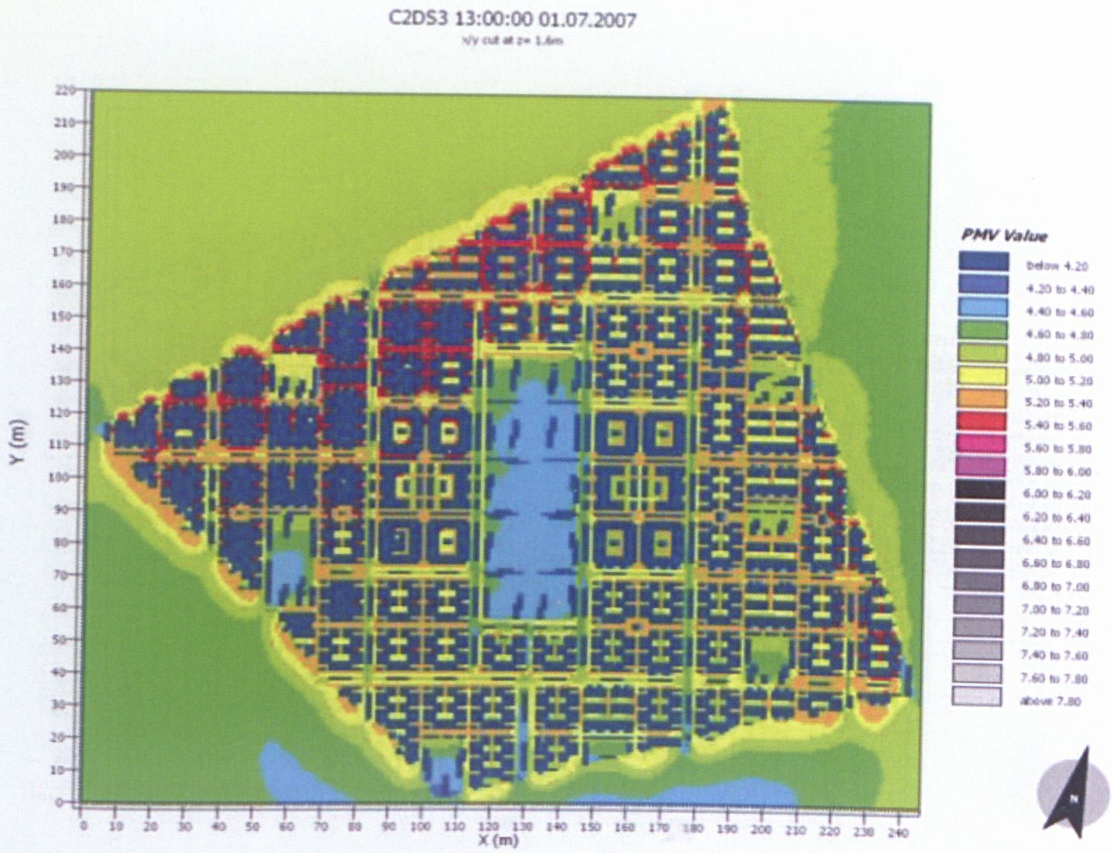


Figure (5-8/g): PMV mapping of C2DS3 1.6m a. g. l. at 13.00 LST.

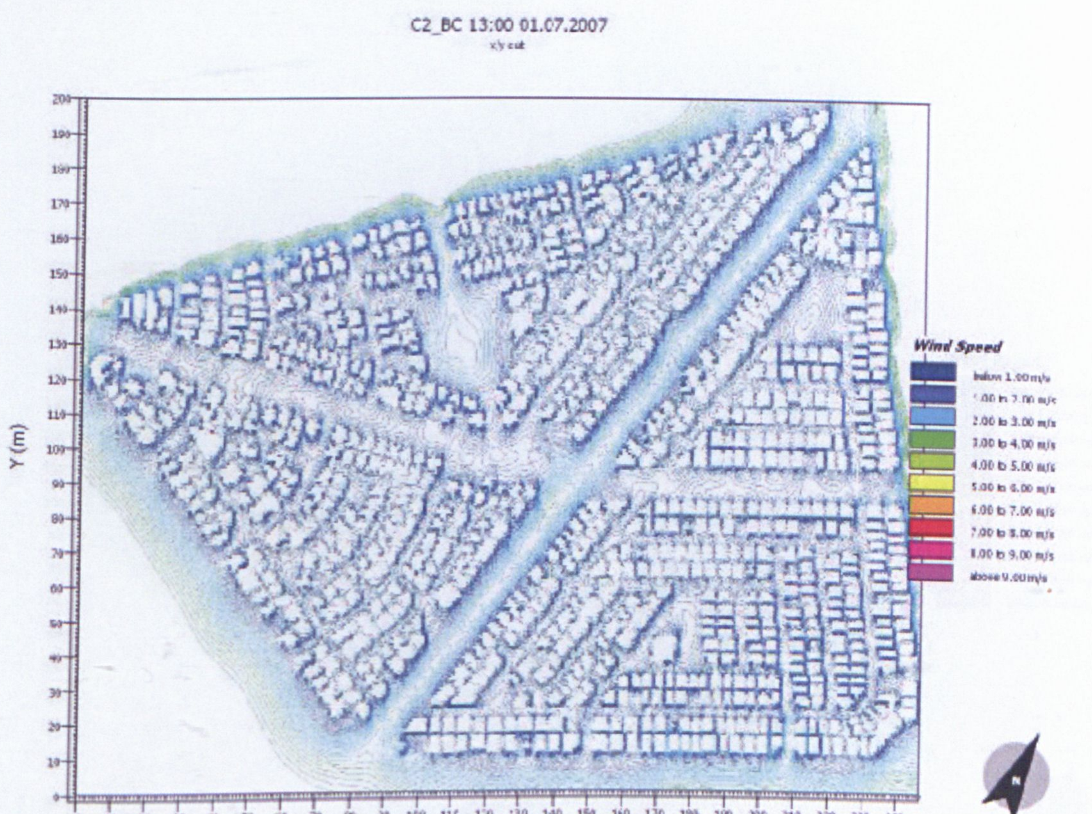


Figure (5-8/h): Wind contours of BC2 1.6m a. g. l. at 13.00 LST.

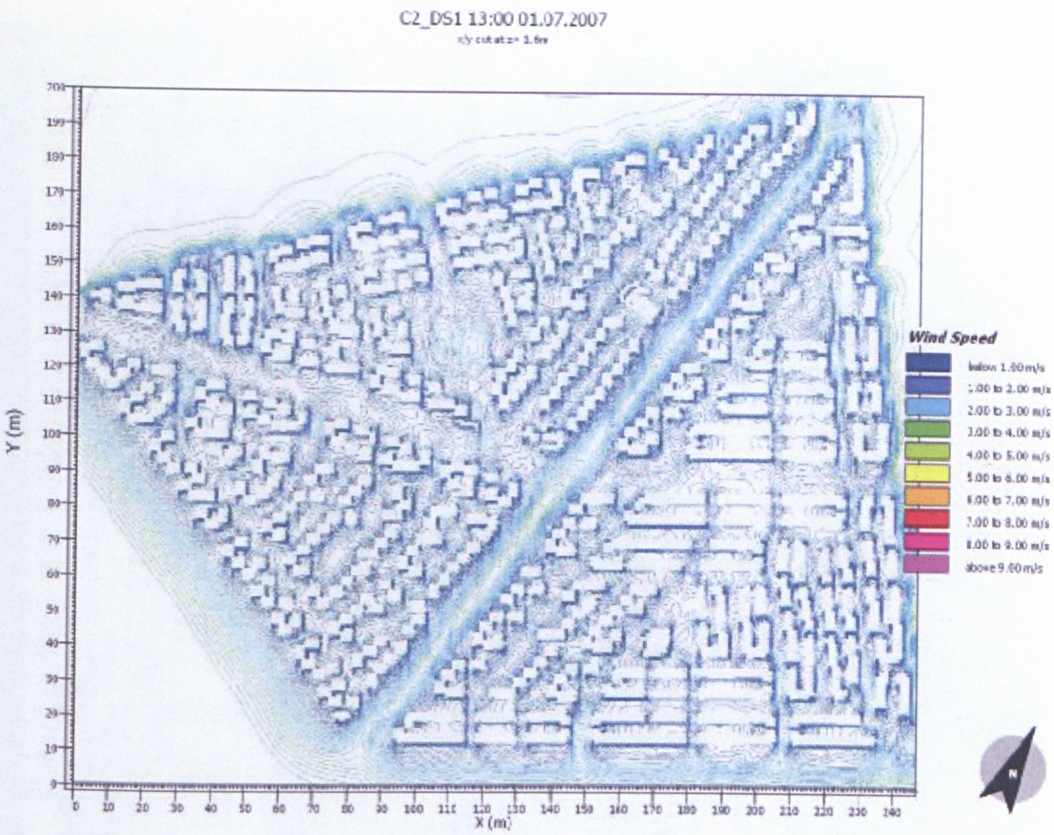


Figure (5-8/i): Wind contours of C2DS1 1.6m a. g. l. at 13.00 LST.

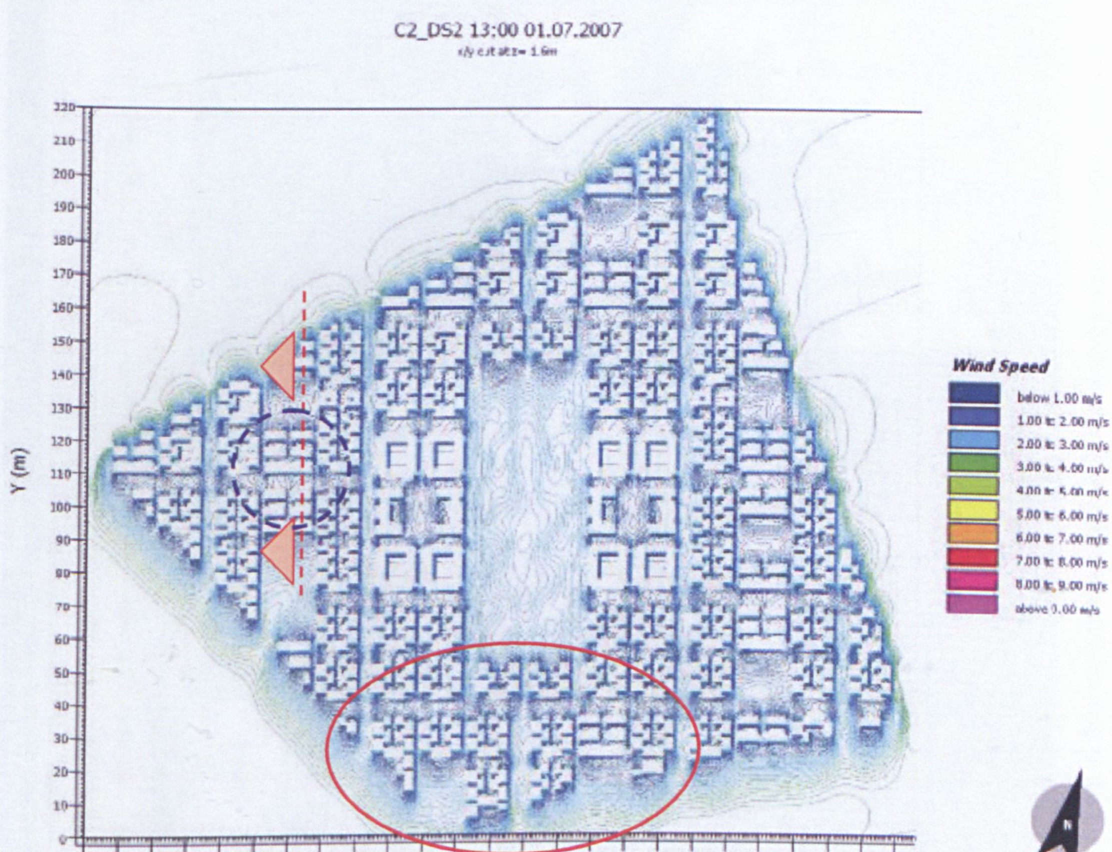


Figure (5-8/j): Wind contours of C1DS2 at 13.00 LST. The section and ellipse are illustrated in fig (5-8/k, l).

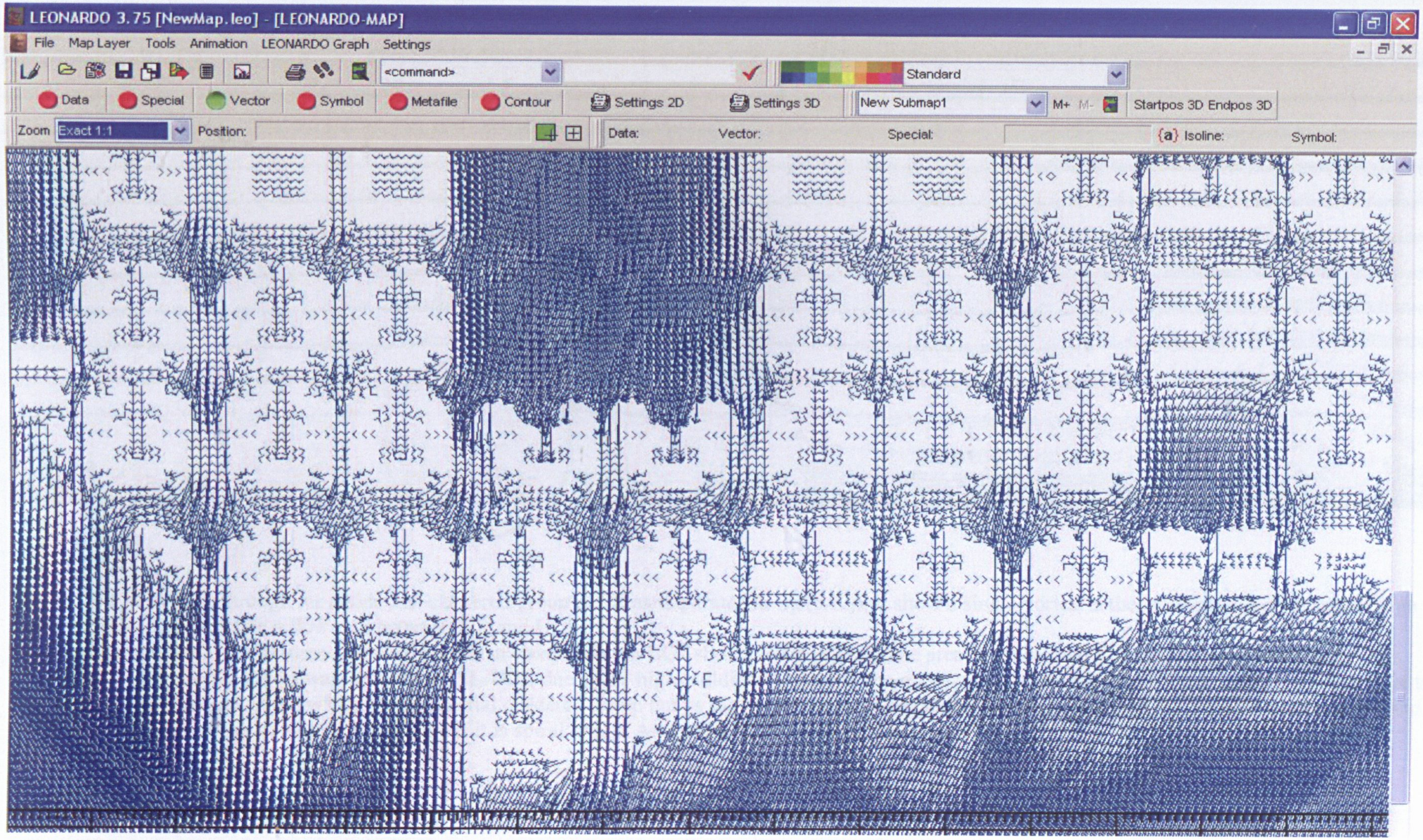


Figure (5-8/k): A flow capture from fig (5-8/j) showing the wind tunnelling effect in the canyons and clusters turbulences of C2DS2, 1.6m a.g.l. at 13.00 LST.

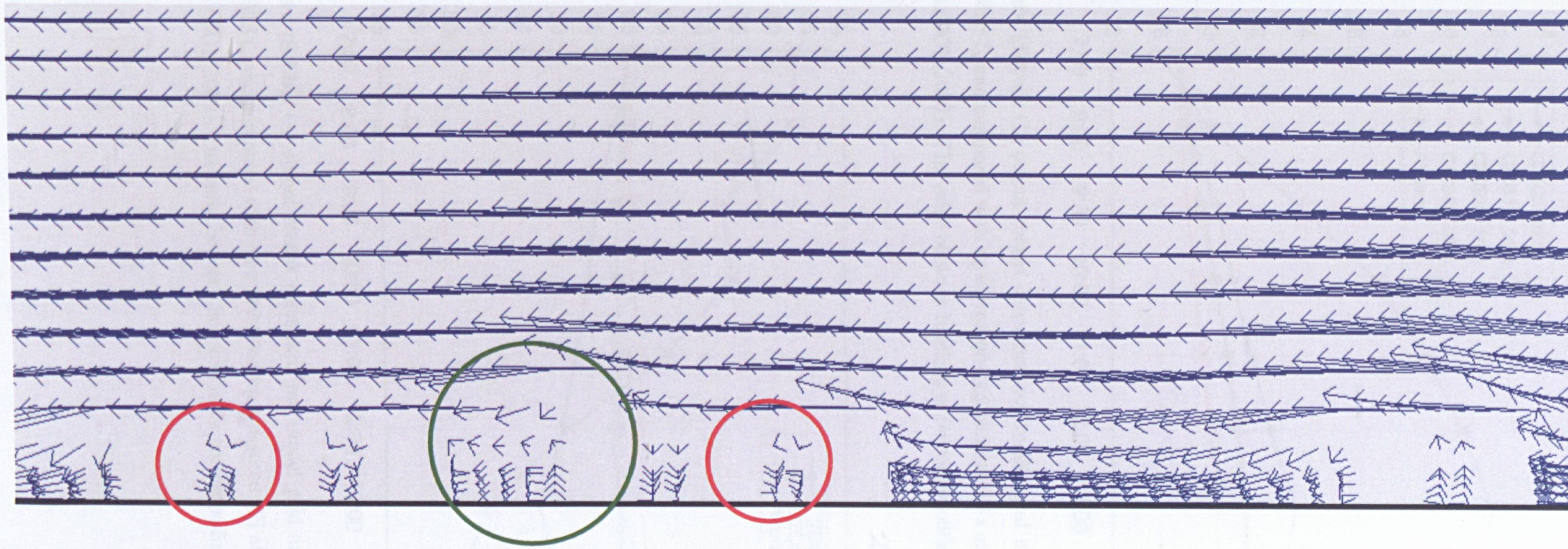


Figure (5-8/l): Section through the residential clustered group of C2 as illustrated in fig (5-8/j), it show a single vortex in the leeward canyon of one of high buildings placed to stimulate a flow mix between ISL and UCL.

This skimming regime allows increased wind speeds in comparison to BC2 shown in fig (5-9/c). The area at the middle is the clustered group garden.

The green circles indicate the leeward mixing of ISL-UCL due to the high buildings located in the master plan whereas the red circles indicate vortices due to the canyons aspect rations of 0.6 within the residential clustered group but as the wind is not at a perpendicular angle of attack, the vortices are not complete circular as in C1, there was no way to investigate if it is spiral or not. Arrows indicate the direction.

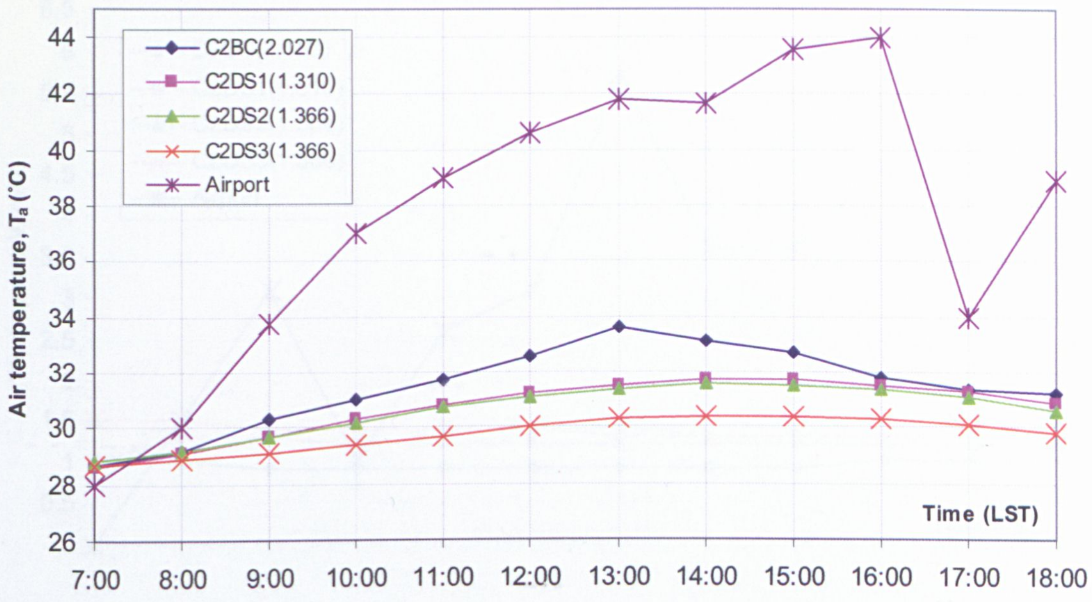


Figure (5-9/a): C2 output means calculated per model grid number using PolygonPlus for Ta from 7:00-18:00LST, and compared with its corresponding measured Ta at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***Dc*** corresponding to each master plan.

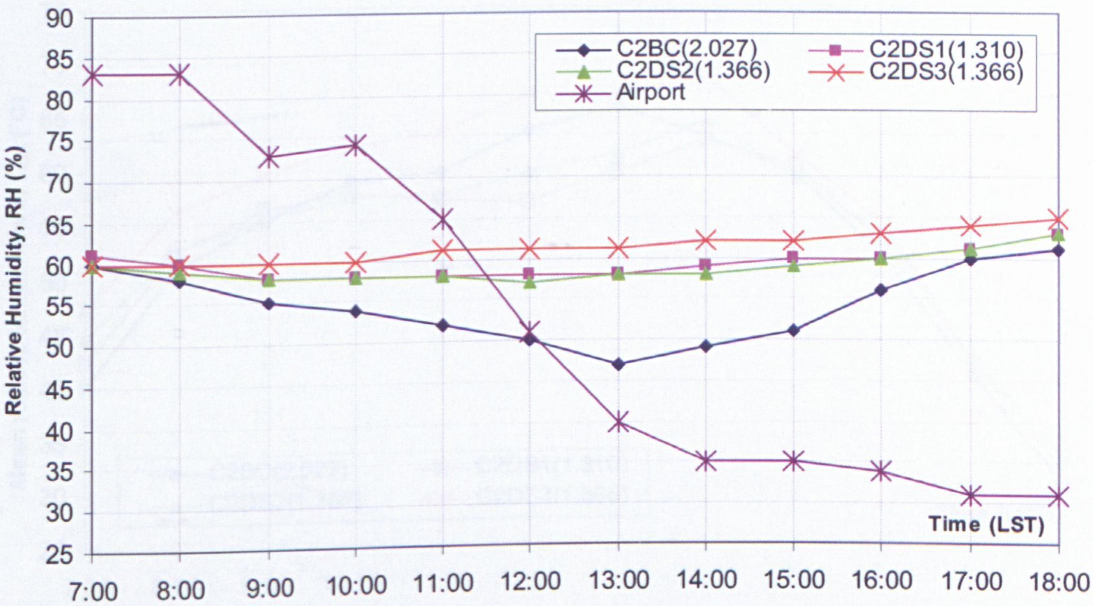


Figure (5-9/b): C2 output means calculated per model grid number using PolygonPlus for RH from 7:00-18:00LST, and compared with its corresponding measured RH at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***Dc*** corresponding to each master plan.

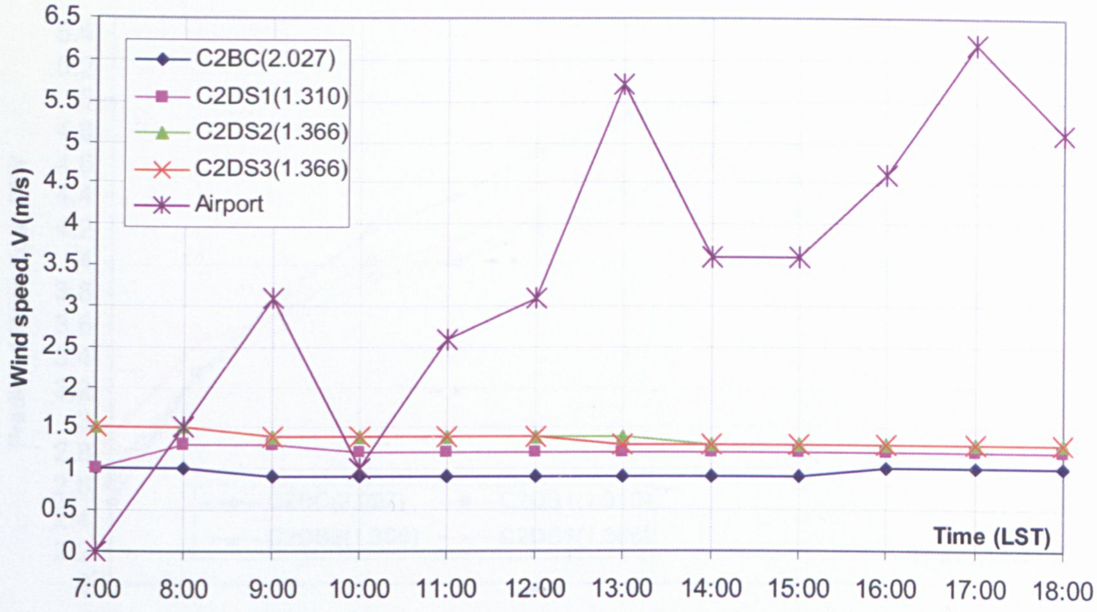


Figure (5-9/c): C2 output means calculated per model grid number using PolygonPlus for V from 7:00-18:00LST, and compared with its corresponding measured V at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***Dc*** corresponding to each master plan.

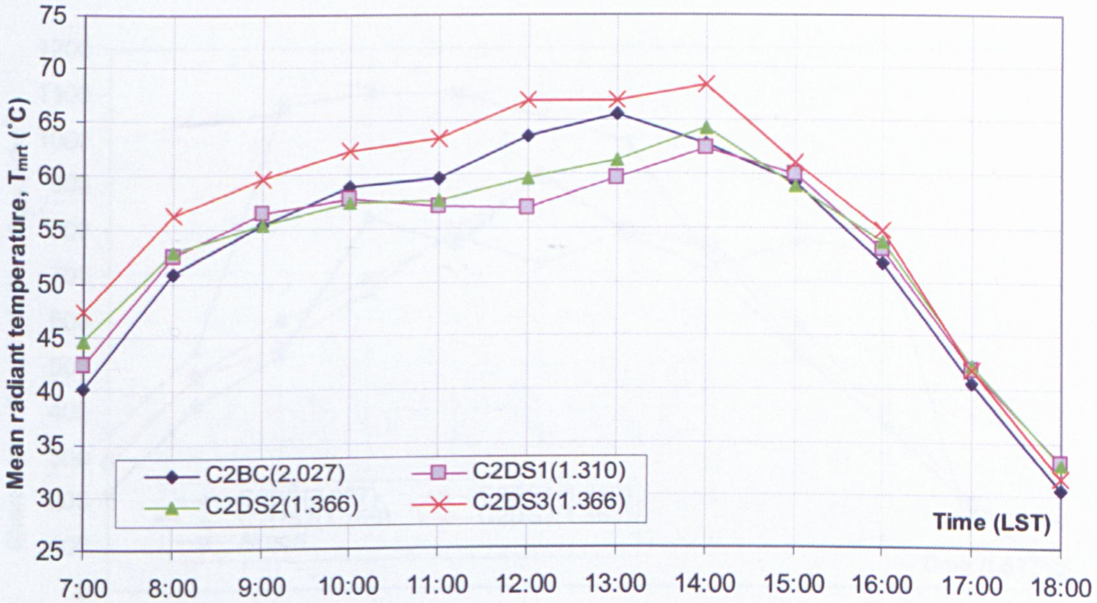


Figure (5-9/d): C2 output means calculated per model grid number using PolygonPlus, T_{mrt}. The value between brackets is ***Dc*** corresponding to each master plan.

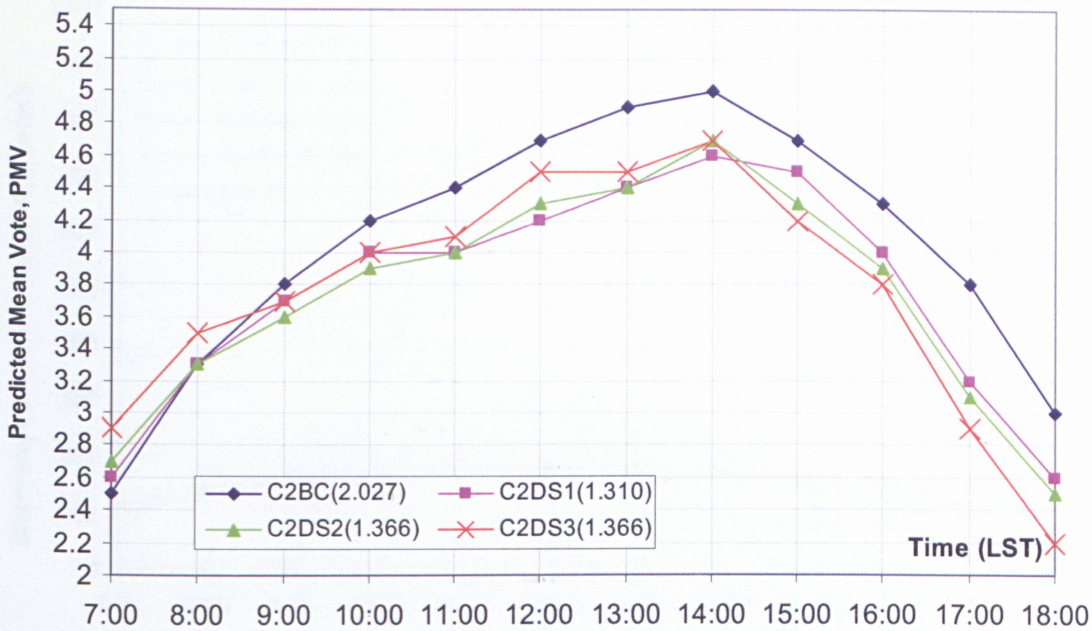


Figure (5-9/e): C2 output means calculated per model grid number using PolygonPlus, PMV comfort levels. The value between brackets is ***D*c** corresponding to each master plan.

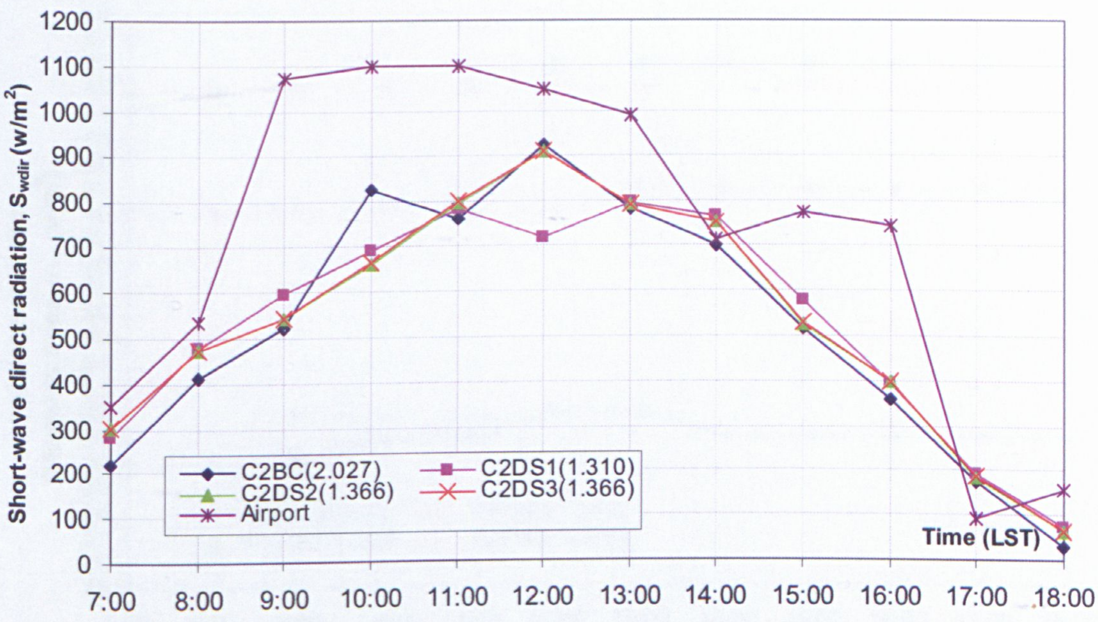


Figure (5-9/f): C2 output means calculated per model grid number using PolygonPlus for Short-wave direct radiation from 7:00-18:00LST, and compared with its corresponding measured Short-wave direct radiation at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***D*c** corresponding to each master plan.

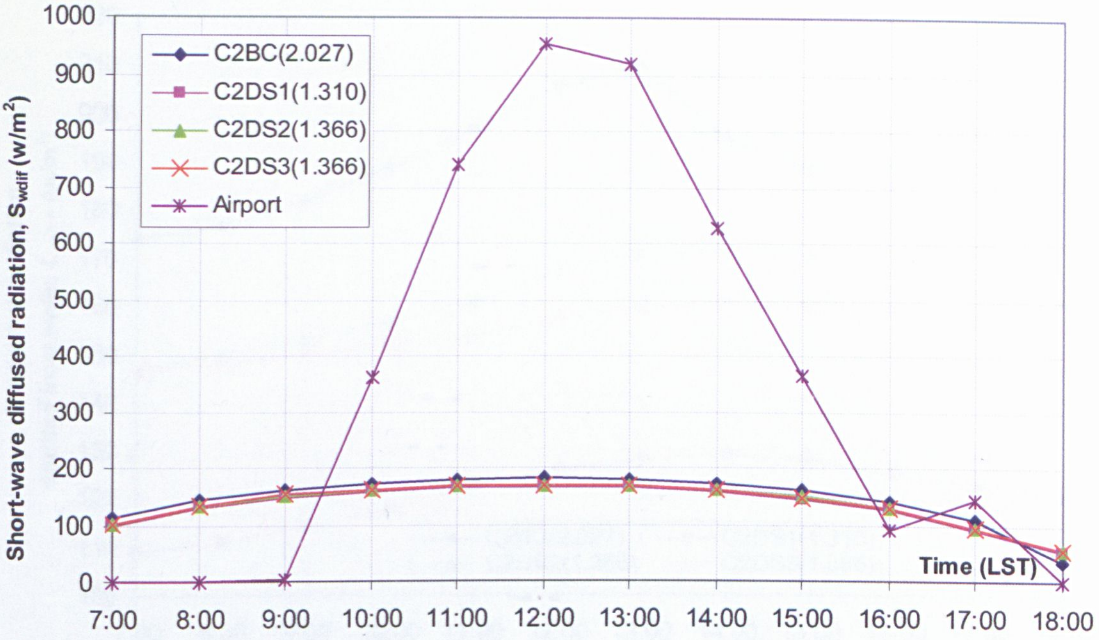


Figure (5-9/g): C2 output means calculated per model grid number using PolygonPlus for Short-wave diffuse radiation from 7:00-18:00LST, and compared with its corresponding measured Short-wave diffuse radiation at Cairo International Airport which is adapted from (DOE 2009). The value between brackets is ***D*c** corresponding to each master plan.

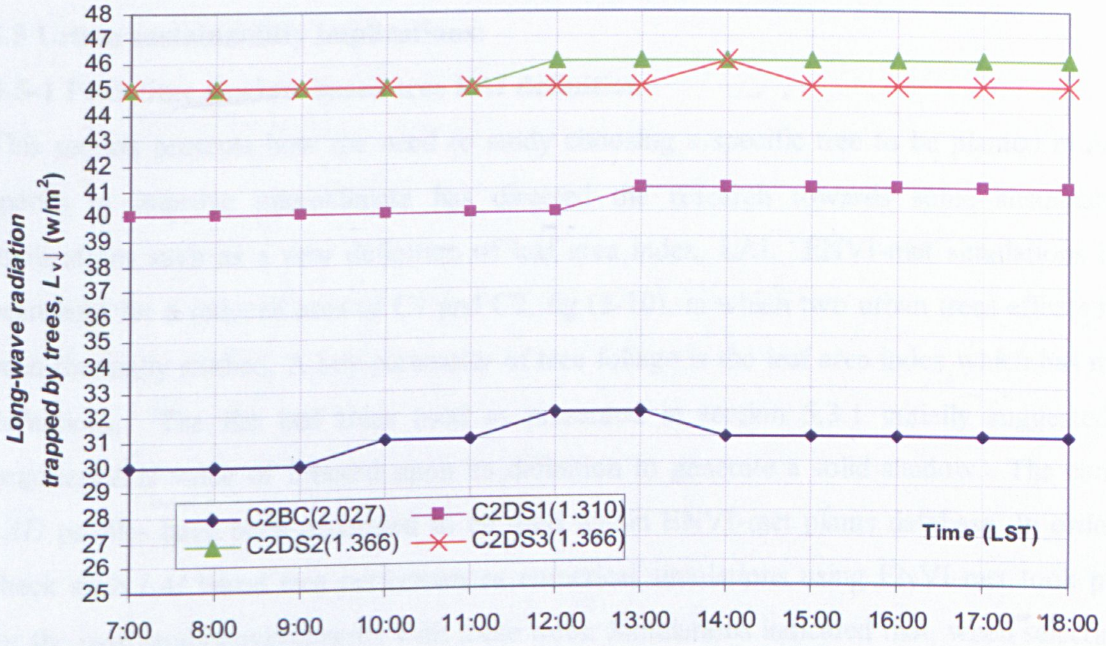


Figure (5-9/h): C2 output means calculated per model grid number using PolygonPlus, Long-wave trapped radiation by vegetation. The value between brackets is ***D*c** corresponding to each master plan.

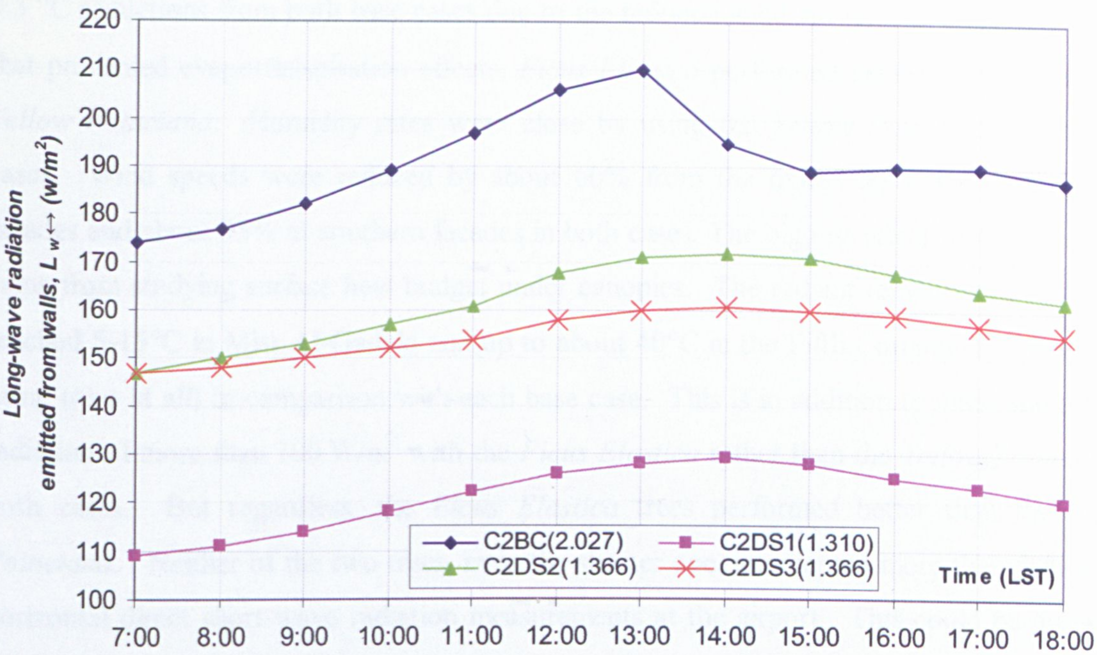


Figure (5-9/i): C2 output means calculated per model grid number using PolygonPlus, Long-wave emitted radiation from fabric. The value between brackets is ***Dc*** corresponding to each master plan.

5.5 Urban sustainability implications:

5-5-1 Peak time shadow based tree LAI definition

This section presents how the need to study choosing a specific tree to be planted in urban spaces to improve microclimate has directed the research towards some sustainability implications such as a new definition of leaf area index, LAI. ENVI-met simulations have been held for a reduced area of C1 and C2, fig (5-10), in which two urban trees effects have been thermally studied. A key parameter of tree foliage is the leaf area index which has many definitions. The flat leaf trees used as presented in section 5.3.1 initially suggested an empirical *LAI* value of 1 based upon its definition to generate a solid shadow. The canopy *LAD* profiles have been generated to be used within ENVI-met plants database. In order to check such *LAI* based tree performances numerical simulations using ENVI-met took place for the case study environments with these trees. Simulations indicated that, when selecting a tree, the greater the tree height then the greater the need to increase leaves to produce more density for more interception (with the caution regarding long wave radiation trapped by canopies). Optimization between ground surface physical properties and the amount of heat trapped by a tree could help increase the *LAI* value of a specific tree so that more direct and sky radiations can be intercepted. Although air temperature records showed only about 0.1-

0.3 °C reductions from both base cases due to the reduced wind speeds and lack of soil water that prevented evapotranspiration effects, *Ficus Elastica* performed generally better than the *Yellow Poinciana*. Humidity rates were close by using the *Yellow Poinciana* or the base cases. Wind speeds were reduced by about 60% from the model input value at northern facades and about 95% at southern facades in both cases. The biggest effect of *Ficus Elastica* came from studying surface heat budget under canopies. The radiant temperature reductions reached 5-15°C in Misr Al-Gadida and up to about 40°C in the Fifth Community (that wasn't using trees at all) in comparison with each base case. This is in addition to intercepted direct radiation of more than 100 W/m^2 with the *Ficus Elastica* rather than the *Yellow Poinciana* in both cases. But regardless, the *Ficus Elastica* trees performed better than the *Yellow Poinciana*. Neither of the two trees, even the shorter one, intercepted more than 50% of the horizontal direct short-wave radiation measurements at the airport. This could be due to an overestimation by the software and integrations of Eq. 18 and 190. It is expected that the smaller the tree height the more dense its shadow. An *LAI* of 1 can be considered the lowest value to intercept about half of the short wave direct radiation by using up to a 20m high flat leaf tree (such as the *Yellow Poinciana*); larger *LAI* values could have intercepted more incoming radiation. Results suggest an actual definition of *LAI* for flat leaf shadow production trees to be in terms of height regardless of its type and in terms of the peak time solid shadow rather than the changeable upper leaf area, i.e. specific definition for each trees range of h and z_m. For a 15m height tree for example; it is three times its ground solid shadow area at peak time. Hence, if the *Yellow Poinciana* examined in this paper is to be used for a housing height up to 20m, it may be not less than *LAI* of 4 should be this tree to intercepting about 100% of incoming radiation. This way can solve the discrepancies of *LAI* definitions reported by (Jonckheere et al. 2004). The study also indicated that, to interpret an actual *LAI* value for a shadow production flat leaves tree with a specific foliage proportions, methodologically, first; test the empirical value *LAI* of 1 to model the tree. At a semi-arid mid-latitude regions starting from 30°N like Egypt and towards low-latitude sites, any tree of h, L_m, and z_m if does not validate *LAI* of 1, the ground shading will not fulfil at least 50% interception and this value can be used as a benchmarking reference for urban trees selection. For other climate regions the empirical start for *LAI* will be 0.5. Second, simulate this tree environment and calculate its corresponding climate effects to initially find the preferable tree among others. Third, estimate its approximate 100% interception *LAI* value then search the market for such trees.

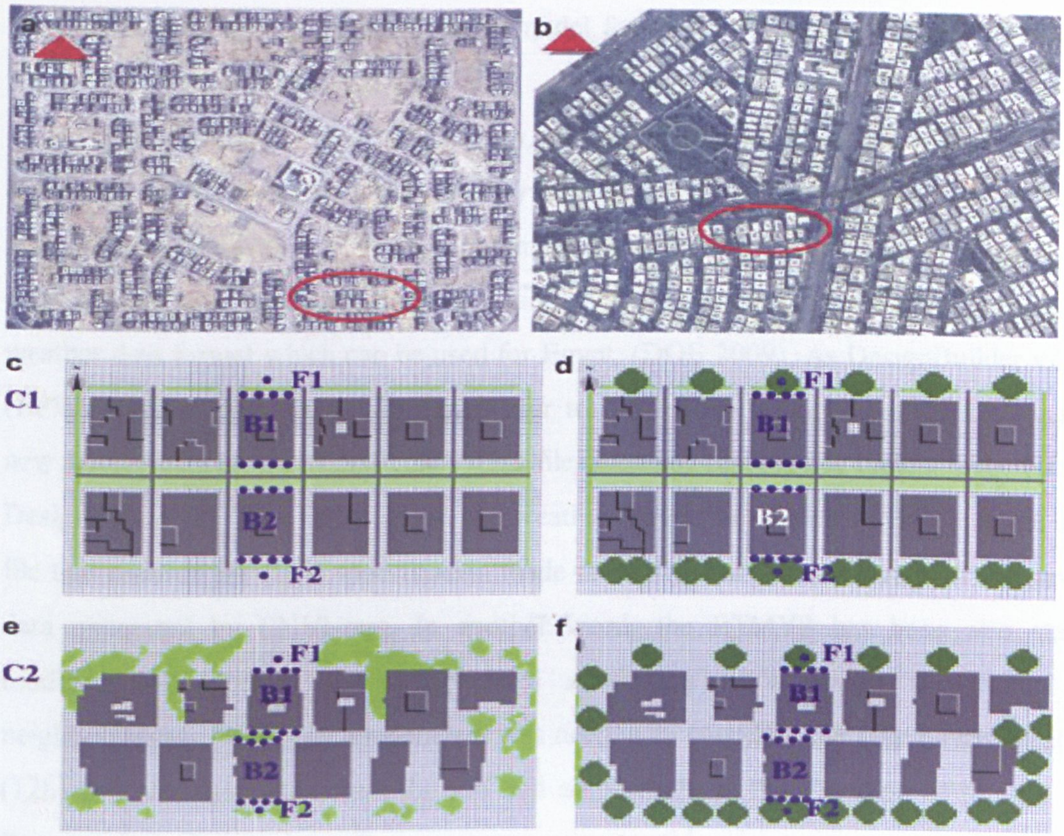


Figure (5-10): Reduced areas investigated from C1 and C2, published in (Fahmy et al. 2010).

5-5-2 Coupling outdoor-indoor simulations and the urban thermal mass

As ENVI-met does not have the capability to simulate indoor climate (it just deals with it as a heat sink through steady state conduction), DesignBuilder2.0.5 has been used for investigating the mean comfort level and CO_2 emissions for a selected building in C1 to study the effect of passive urban planning on CO_2 emissions. DesignBuilder v2.0.5 is a 3-D comprehensive interface built over Energy Plus v3.1, (DOE 2009), a dynamic model that can simulate indoor thermal interactions, calculate comfort levels and CO_2 production (DesignBuilder 2009).

The building is designed as a ground + two floors (G+2) dwelling, built in 2006 as a small multifamily unit containing almost 6 typical flats each with 5 people per flat. The ground floor area is 300m^2 where typical floors are 330 m^2. It has a window to wall ratio of about 15% and it is oriented along the N-S axis. Despite the building already existing in BC1, it has been assumed that the same building will be constructed in all C1DS1-3 in order to fix differences in CO_2 production to the built environment not to the increased facilities if a (G+3) of the C1DS1-3 has been used. The mechanical cooling system is split with separate mechanical ventilation in a multi zones model for all zones except for bathrooms, kitchens, stair cases and the whole basement.

The means of *air temperature, wet bulb temperature, relative humidity, global radiation, short-wave direct and diffuse radiations and wind speed* for all site outdoor grids were added in their time places in a comma separated (CSV) file extension. This allow easy editing of hourly meteorological data in an Egyptian Typical Meteorological Year (ETMY2) weather data format which can be used for Egypt, (DOE 2009). As DesignBuilder v2.0.5 uses (EPW) weather files, EnergyPlus converter tool has been used for conversion after writing new hourly data in the (CSV) file. This file does not represent a typical year, but actually DesignBuilder v2.0.5 cannot upload the weather file for simulation without using a statistical file that records the slight modification made to the typical year by means of the new hourly data generated by ENVI-met. In another word, the ETMY2 has been also statistically modified to represent the urban form adaptation from design suggestions of the neighbourhood. Wet bulb temperature was needed to complete the new hourly weather data (12h) and was calculated from *T*a, *RH* and air pressure at the elevation of the site (100439 Pascal at 74m above sea level).

The building design temperature is 23°C whereas the ambient air temperatures calculated statistically generated by EnergyPlus and used in DesignBuilder were maxima of 44°C and 43°C for BC1 and C1DS1-3 respectively and minima of 24°C for all of them.

Snapshot receptors were used to record the near wall meteorology for a limited microclimate area in the Fifth Community; the urban site had been simulated in a local scale. Therefore, mean meteorology for the whole site can be representing ambient conditions for all the site's buildings, which is better than using WMO weather station measurements from a single point to represent the climate conditions of a city (WMO no. 623660 at Cairo International Airport weather station). Moreover, this is better than having receptors surrounding each building which means more than the receptor numbers allowed in ENVI-met (99) giving a large number of simulations for each building, which is very time consuming. Simulations for each case in this work took about 7-10 days to build the model, about 7 days to simulate it and about 5 days to extract numerical data, indoor simulations and plot the outputs. Eventually, local scale meteorology means have been used to compile the (EPW) file for use by DesignBuilder, fig (5-11).

Figures (5-12) and (5-13) show mean building indoor comfort level, PMVi and CO_2 production per Kw.h corresponding to mean ambient conditions at 1.6 a.g.l which in turn corresponding to mean outdoor comfort, PMVo of all urban spaces of the neighbourhood at same height. The same trend of PMVo presented in section 5.4 can be noticed in PMVi regardless its close records for all cases owed to the mechanical cooling that kept comfort levels close to each other. Surprisingly, CO_2 produced from DS1 has exceeded that of BC starting from 12.00LST and towards sunset reaching 1.5Kg at 18.00LST. The success that the clustered form of DS1 has achieved in comparison to BC1 appeared in PMVo hasn't been achieved in terms of CO_2 emissions. It used only clustered form without structuring the green coverage or intensively using urban trees and didn't help much modification of ambient climate conditions in terms of PMVo which recorded only 4.9 for DS1 in comparison to 5.1 for BC1. The application of the passive thermal comfort system used by (Fahmy and Sharples 2009a), on a neighbourhood scale with enhanced clustered form oriented 15° from E-W axe as an optimization for mid-latitude location, performed generally better regardless the urban mass effect discussed in 5.4.1. The compiled ambient conditions of DS2 reduced CO_2 production by 1.7% of about 0.6Kg from BC at 13.00LST and start to exceed BC at 14.00LST at which the urban mass effect starts to take place. C1DS2 had maximum day time CO_2 reductions of 1.7Kg at 10.00LST. The only difference of DS3 from DS2 is the roof surfaces' albedo as shown in Table.2. In this suggested master plan, CO_2 reductions at peak time reached 2.8% of about 1.0Kg from BC. In fact, the sum of the 12h CO_2 production for all BC and DS1-3 revealed that only DS3 succeeded in coupling between reduced outdoor-indoor comfort levels and reduced CO_2 production. Despite DS3 CO_2 sum of the 12h equalled 404k.g compared with 404.3Kg for BC1, the small daily sum difference gives an idea about the homogeneity of DS3 urban form. Its compactness could have allowed more nocturnal cooling for each clusters' group within each quarter if the local urban radiant heat island, LUHI, showed improved homogeneity as described by (Fahmy and Sharples 2009a). In another word, more reductions can be achieved by decreasing the urban mass time lag, fig (5-7e), appeared early evening lasting for about 2h from 13.00LST until 15.00LST.

From the author's point of view, street canyons' aspect ratios of the best coupled outputs, DS3, should be more than the used ratio of 1 and 0.6 within cluster groups. Another solution is to use high asphalt albedo of both the asphalt and pavement to reduce heat gain along with minimizing the emitted stored sensible heat but this unfortunately might affect PMVo negatively. Nevertheless, it is not the scope of this work and could be an extension outlining a complete neighbourhood cool surfaces as presented by (Akbari et al. 2001) not only for building roofs as used in DS3.

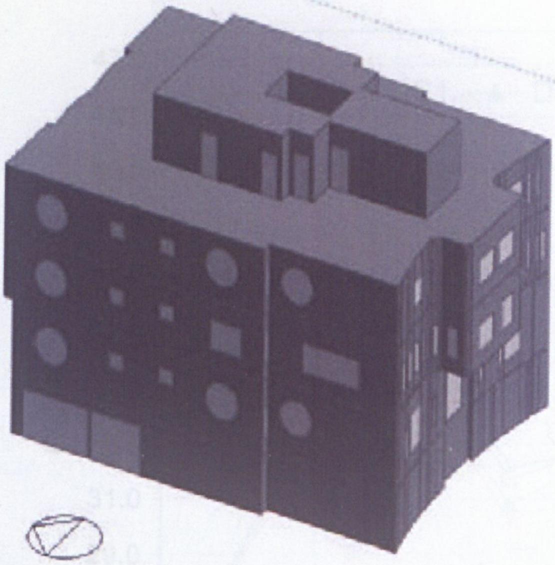


Figure (5-11): The building model built in DesignBuilder2.0.5 including its basement which is not included in CO_2 production calculations (Doesn't have HVAC system).

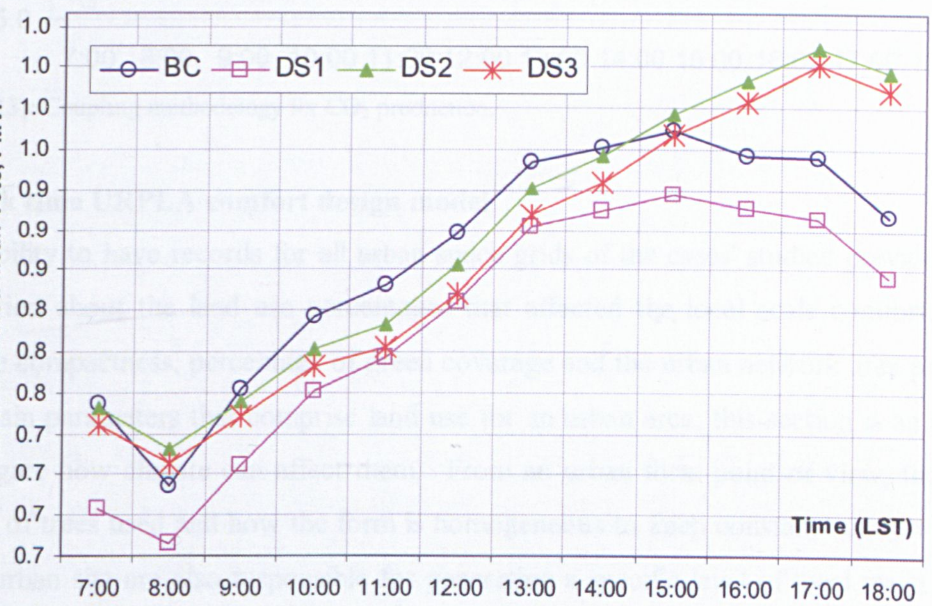


Figure (5-12): Coupling methodology for mean indoor comfort levels.

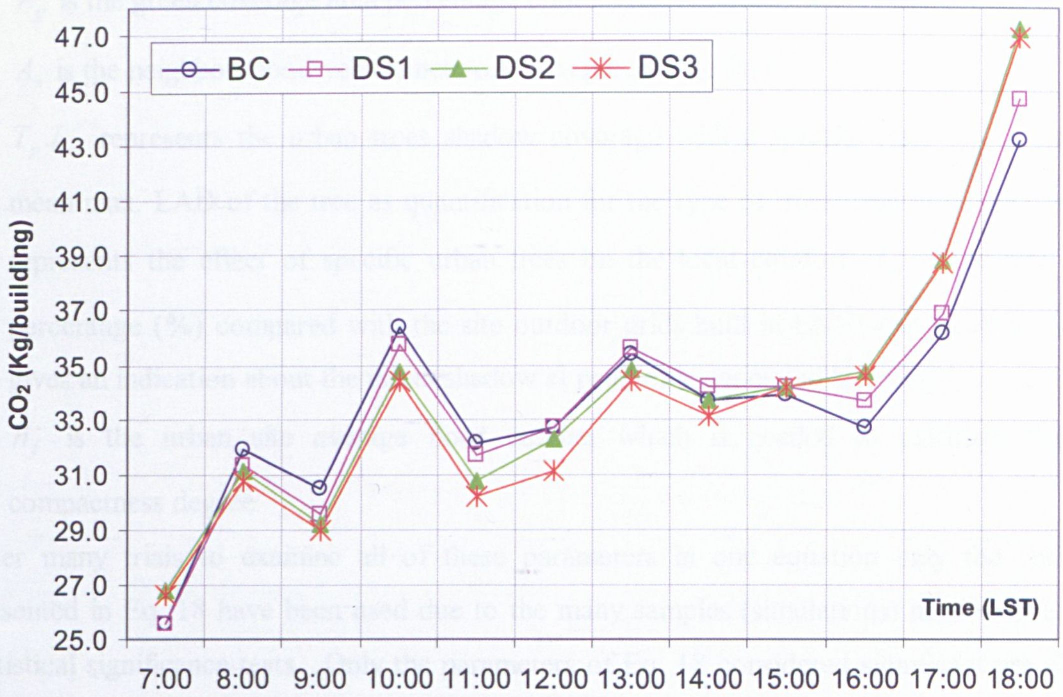


Figure (5-13): Coupling methodology for CO_2 production.

5.5.3 Peak time URPLA comfort design model

The capability to have records for all urban space grids of the cases' studied previously gives an indication about the land use percentages that affected the local scale comfort. As the local scale compactness, percentage of green coverage and the urban network area percentage are the main parameters that comprise land use for an urban area; this section is an approach to investigate how climate can affect them. From an urban form point of view, the number and types of trees used and how the form is homogeneous to keep constant comfort levels all over the urban site are also responsible for generating a specific level of local mean comfort. This section is a presentation of how these can be useful for urban planners and neighbourhood development in terms of the local mean PMV value. For the same fixed surface albedo and thermal conductance values the mean PMV is a result of all the urban spaces PMV values which in turn is a consequence of certain fabric and GreenSect compositions. This design composition can be represented empirically by an equation summing the form design parameters as follows:

1- D_c standing for fabric volume, i.e. residential construction percentage A_c × canopy layer height, or the number of urban floors n_f which in turn can be calculated from the population.

2- A_c is the urban site constructed area percentage.

3- A_g is the green coverage area percentage (%).

4- A_n is the neighbourhood vehicle network area percentage (%).

5- $T_p.L_m$ represents the urban trees shadow coverage with a specific tree. L_m is the site mean max. LAD of the tree as quantification for the type of trees used in the site, which represents the effect of specific urban trees on the local comfort. T_p is the tree grids percentage **(%)** compared with the site outdoor grids built in ENVI-met modeller which gives an indication about the urban shadow at peak time generated by trees.

6- n_f is the urban site average floor number which is needed to calculate the site compactness degree.

After many trials to examine all of these parameters in one equation only the variables presented in Eq. 18 have been used due to the many samples (simulations) needed to qualify statistical significance tests. Only the parameters of Eq. 18 considered significant are shown in tables (5-5) and (5-6). Where more parameters are added such as D_c in the regression applied to derive coefficients, insignificance took place. But such an important parameter could be derived eventually as shown in Eq. 22.

Thus, the initial equation has been written to represent the land use parameters that compose an urban passive system are as follows;

$$URPLA = c_1.A_c + c_2.A_g + c_5.T_p.L_m + c_n \qquad \text{Eq. 18}$$

URPLA; is the urban comfort level at a time in terms of PMV at peak time of the design day.

The Egyptian land use planning policy supposes that about 1/3 of the neighbourhood area is dedicated for network and about 1/4 for civic services, so that the rest of around 50% of the neighbourhood area is for residential usage. This study assumes that the green part of the civic services area is a part of A_g. From this viewpoint, A_g is not calculated as only the public green spaces but also includes the rest of the plot areas. As the maximum plot construction percentage can be 60% for all types of buildings, the real A_c value is about 60% of the area dedicated as residential of a neighbourhood residential plot area R_c. So if an assumption is made to fix A_n at 40%, an optimization for the land uses relation of A_c (fabric) and A_g (GreenSect) can be made on a climatic basis after deriving regression coefficients.

As a note, the three percentages of A_c, A_g and A_n are the main compositions of an urban land use so that:

$$R_c + A_g + A_n = 1 \qquad \text{Eq. 19}$$

$$1.4A_c + A_g + 0.40 = 1 \qquad \text{Eq. 20}$$

The model coefficients have been derived by regression analysis using outputs of 14 simulations but only the results of two hours at the peak time for each sample have been used. The basic designs illustrated in table (5-4) have been used in addition to modifications in D_c and in $T_p.L_m$ in terms of more floors added and a different tree used as indicated in table (5-5) and fig (5-14/a). First of all, ENVI-met's overestimations do not allow comfort prediction by night, therefore only the day time which is about 12 hours in summer at a mid-latitude location like Cairo, has been simulated. Among these 12 hours a couple hours of the peak time PMV mean was selected in the regression step to generate the model coefficients, which theoretically, if solved later, will generate land use parameters to cope with the peak climate conditions. Therefore;

$$URPLA = c_1.A_c + c_2.(0.6 - 1.4A_c) + c_3.T_p.L_m + c_n \qquad \text{Eq. 21a}$$

To solve the model for specific climate conditions and a site, the corresponding PMV along with vegetation and urban planning parameters have to be entered. PMV as an URPLA value is calculated as comfort conditions for a design day (typical or extreme summer day at peak time) are known whereas the needed T_{mrt} is assumed to equal air temperature for that day and time. Other biometeorological entries are for a walking pedestrian with speed of 1.1 m/s and 0.5 Clo.

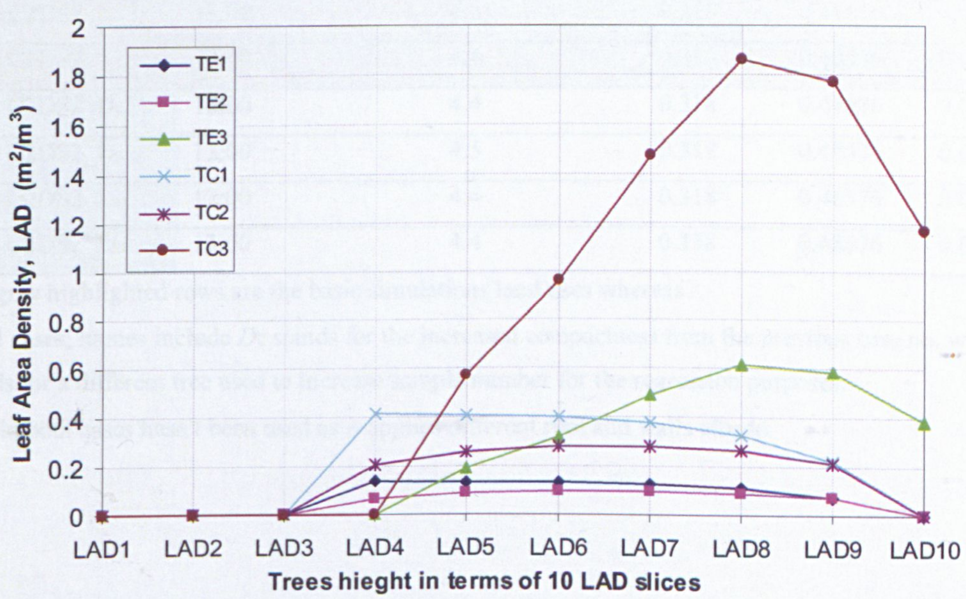


Figure (5-14/a): 10 LAD values of the trees used in thesis simulations; L_m, i.e. the maximum LAD for each tree was selected to represent the urban tree type in the model.

Table (5-6): Samples of URPLA regression.

No.	Samples	Output Time (LST)	URPLA (PMV)	A_c (%)	A_g (%)	$T_p.L_m$
1	C1BC	12:00	5	0.252	0.36757	0.01364
2	C1BC	13:00	5.1	0.252	0.36757	0.01364
3	C1DS1	12:00	4.8	0.299	0.29117	0.02015
4	C1DS1	13:00	4.9	0.299	0.29117	0.02015
5	C1DS1_Dc	12:00	4.5	0.299	0.29117	0.02015
6	C1DS1_Dc	13:00	4.6	0.299	0.29117	0.02015
7	C1DS1_Lm	12:00	4.3	0.299	0.29117	0.04161
8	C1DS1_Lm	13:00	4.3	0.299	0.29117	0.04161
9	C1DS2	12:00	4.3	0.310	0.47620	0.06003
10	C1DS2	13:00	4.7	0.310	0.47620	0.06003
11	C1DS2_Dc	12:00	4.1	0.310	0.47620	0.06003
12	C1DS2_Dc	13:00	4.3	0.310	0.47620	0.06003
13	C1DS2_Lm	12:00	4	0.310	0.47620	0.04132
14	C1DS2_Lm	13:00	4.3	0.310	0.47620	0.04132
15	C2BC	12:00	4.7	0.412	0.10471	0.22878
16	C2BC	13:00	5.2	0.412	0.10471	0.22878
17	C2DS1	12:00	4.2	0.327	0.27299	0.02984
18	C2DS1	13:00	4.4	0.327	0.27299	0.02984
19	C2DS1_Dc	12:00	4.3	0.327	0.27299	0.02984
20	C2DS1_Dc	13:00	4.4	0.327	0.27299	0.02984
21	C2DS1_Lm	12:00	4.3	0.327	0.27299	0.05358
22	C2DS1_Lm	13:00	4.3	0.327	0.27299	0.05358
23	C2DS2	12:00	4.3	0.318	0.48576	0.05175
24	C2DS2	13:00	4.4	0.318	0.48576	0.05175
25	C2DS2_Dc	12:00	4.4	0.318	0.48576	0.05175
26	C2DS2_Dc	13:00	4.5	0.318	0.48576	0.05175
27	C2DS2_Lm	12:00	4.4	0.318	0.48576	0.03562
28	C2DS2_Lm	13:00	4.4	0.318	0.48576	0.03562

- The grey highlighted rows are the basic simulations land uses whereas
- In all cases; names include *Dc* stands for the increased compactness from the previous case no. whereas L_m stands for a different tree used to increase sample number for the regression purposes.
- DS3 in both cases hasn't been used as it applies different roof and walls albedo.

Table (5-7): Statistical significance tests for regression variables.

	Regression Coefficients' Statistics for Significance				
		A_c (%)	**A_g (%)**	**$T_p.L_m$**	**C_n**
1	Coefficients	-11.39138006	-0.993456605	7.00855659	8.074564453
2	Standard error (x)	3.379198718	0.578592109	2.25344412	1.00537105
3	Standard error (y)		0.251931229		
4	Correlation (r^2)		0.513061854		
5	df		16		
6	Hypothesis		0		
7	f-critical ($F \leq f$)		4.264 (0.01)		
8	F-statistic		7.224987		
9	t-critical ($T \leq t$)	2.92078 (0.005)	1.336757 (0.1)	2.92078 (0.005)	4.0150 (0.0005)
10	T-statistic	-3.371029942	-1.717024117	3.110153266	8.031427254

- The standardized coefficient of significance for f-critical and t-critical corresponding to each land use variable is in between brackets of rows 7 and 9.

T_p is assumed by not more than $0.5(A_u - A_c)$ to allow an optimization between minimizing exposure time and releasing the trapped heat. On this basis it can be easily calculated from the model area file grids. This is regardless of the fact that ENVI-met trees grids overlap A_g grids. Therefore, to use Eq.20 for land use parameters prediction, it can be written as following;

$$URPLA = -11.39138A_c - 0.99345(0.60 - 1.4A_c) + 7.00855T_p.L_m + 8.07456 \quad \text{Eq.21/b}$$

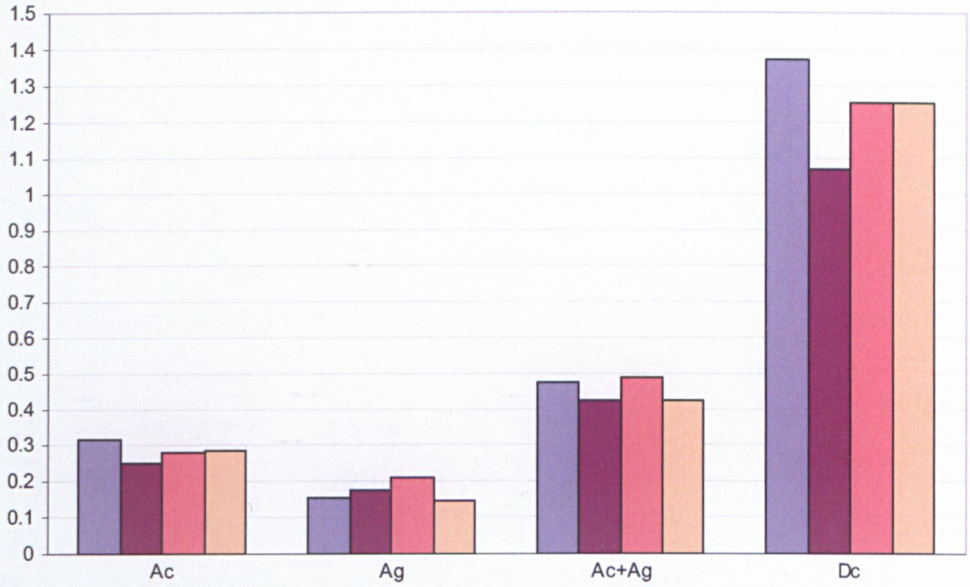
Consequently:

$$A_c = (URPLA - 7.00855T_p.L_m - 7.47849)/(-10.00055) \quad \text{Eq.22/a}$$

And hence;

$$D_c = n_f.[(URPLA - 7.00855T_p.L_m - 7.47849)/(-10.00055)] \quad \text{Eq.22/b}$$

This URPLA model has been validated against the designs presented by (Fahmy and Sharples 2009a) and shown to have a good prediction for the original design parameters used after considering revising the actual grids in the model area file to calculate land use percentages rather to calculate them from AutoCAD files. Figure (5-14/b) show the resulting A_c, A_g and their sums for the same population, climate conditions and vegetation used in (Fahmy and Sharples 2009a) in comparison to the predicted values by URPLA.



	Ac	Ag	Ac+Ag	Dc
Predicted Means S1	0.316755146	0.156542796	0.473297942	1.36940916
Original Means S1	0.24774	0.176	0.42374	1.068
Predicted Means S2	0.280039175	0.207945155	0.48798433	1.255834562
Original Means S2	0.28388	0.143	0.42688	1.255

Figure (5-14/b): URPLA validation; Predicted Ac and Ag plotted against their originals simulated.

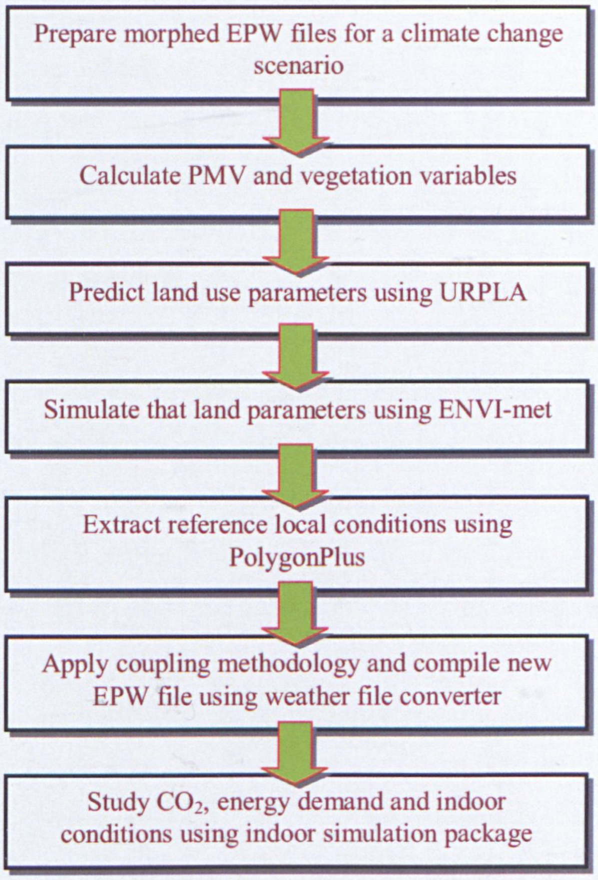


Figure (5-15): Future form prediction flow chart and software cycling.

Eventually and as shown in fig (5-15), software cycles can be introduced to predict future urban form land uses, indoor comfort and energy demand studies due to climate change. Such an approach does not completely exist on the ground of climate change literature and its related consequences until now. But this could take more time to simulate more cases of refining URPLA validations to be used in such methodology and needs the developed version of ENVI-met to simulate 24h of the design day instead of only being limited to day time.

Chapter Six: Conclusions and Recommendations

6-1 Concluding remarks:

Directly, thesis rolled around climate based urban planning in Cairo and its benefits for wellbeing in terms of human outdoor thermal comfort as well as energy saving in terms of controlling solar access to reduce the whole urban pattern heat gain. These two main objectives couldn't be approached unless urban thermal comfort and urban planning basics have been studied in a broadened way to know how to design an urban pattern and fabric that interact passively to generate a specific urban form. A mutual iterative design method took place between the urban form in terms of passive design tools and with assessment to enhance both of urban spaces details. By this way the awareness for the necessity of a new urban planning renaissance based on passive thermal design of urban patterns can be raised. As the combination of assessing human comfort within built environment is crucial to know how much the design is successful, an analysis using one of the numerical models that can simulate almost a complete urban environment, ENVI-met, simulations were held for two local scales urban forms for summer typical day time which revealed urban planning implications.

Urban passive design tools presented in chapter two have been embedded in newly suggested forms, simulated and then compared with base cases. These design tools can be grouped as pre-planning and design stage tools such as site selection. While-design tools' group is concerned about the fabric, i.e. the buildings themselves, how they can be formulated using the pattern type and degree of compactness which can be considered the fabric form adaptor. Urban GreenSect is another important tool of this second group, it is a green structure based on the human biometeorology. It helps directing the land use zoning and the initial neighbourhood sketch design towards specific urban form instead of just planning to accommodate population. Thirdly, using cool surfaces including green roofs is the third group which doesn't affect the form itself nor improving the human thermal comfort rather than reducing fabric heat gain within large scale revealing in energy saving.

However, literature and pre-main simulations guided the suggested design towards the clustered form combined with medium population and concluded what the research called it, hybrid urban form. From this standing point, the first case; the Fifth Community, is less populated due to the single family dot patterned housing which revealed more wind access as well as more solar as presented previously. Contrary, second case; Misr Al-Gadida, is over populated revealed high rise apartment residential buildings with more solar and wind shelter.

Consequently, hybrid urban form increased population in the first case and the opposite in the second in order to offer a medium population urban form which is same time offered controlling the local urban climate circumstances and its thermal performance. Two main suggested urban clustered forms were simulated for each case study with parallel shaded-unshaded avenues; the first one was built over the existing site zoning whilst the second was a new design. Second suggestion for each case is a proportionally refined clustered form built all over the neighbourhood site. The clusters' courtyard proportion is 1:3:1.3 as W/L/H with a closure ratio of 3.45.

The GreenSect (Green coverage within city tranSect) as a passive urban planning tool that is mainly an urban green pattern regularly distributed all over the neighbourhood. Distances between green nodes have been calculated biometeorologically using human walking speed and the time of walking which can be related in further studies to the exposure time, so that quantification for the human comfort adaptation aspects can be offered. Comfort in terms of PMV has been improved from both base cases by peak time using the clustered fabric and the GreenSect. Long-wave radiation from environment elements; ground, walls and trees illustrated more improvements but cautious has to be given to the trapped heat either by the more compacted fabric or by the more dense trees.

Numerically calculated and introduced to ENVI-met in terms of its maximum peak time ground shadow, sites' urban trees effects significantly appeared in the Fifth Community design suggestions. This is owed to the lack of existing trees in situ revealing the shift in the plotted curve of PMV and radiant temperature which had a name by the research as urban thermal mass. Therefore, the more urban thermal mass, i.e. more number of specific trees' species, the more shift on the urban PMV mean is expected. Regardless that PMV is literally criticized in comparison to other comfort scales, but the modifications to include direct solar radiation illustrated in chapter one made by (Jendritzky and Nübler 1981) allowed using PMV in ENVI-met sufficiently. Increasing albedo values for surfaces didn't help more comfort closure rather than more surfaces' temperature reduction, air temperature reductions and hence better indoor thermal performance is expected.

Main remarks as presented in this study are:

1- Local climate scale control to improve outdoor comfort as well as energy savings have to be approached by specific combination of urban passive design tools not only fabric design aspects, nor only vegetation aspects. Based on population density, passive thermal comfort system is mainly composed of a parallel avenued hybrid clustered fabric, GreenSect and the human comfort adaptation aspects. From another sustainability point of view, adaptation opportunities for people can be offered through urban passive design contributed to behavioural adjustments which increases urban habitat, privacy for enclosed urban spaces and variety of urban places that appear within this new pattern; the micro GreenSect at each residential clusters' groups. Such a parallel avenued clustered fabric with GreenSect patterned neighbourhood can be considered a climate based urban planning improvement for the Garden city as it has the residential clusters' groups arranged around the biggest part of the GreenSect but with different approach and concluded urban form, it can be called a climate neighbourhood.

2- Optimization for pedestrian solar exposure time can be further studied, so that using pedestrian walking speed and the minimum exposed distance to walk through, the time of exposure can be quantified as another human urban thermal comfort adaptation aspect. This was out of this study scope as it needs simulations for pedestrians' movements in the urban environment in order to support the decision of route choosing based on the ground shadows at peak time which is supposed to be the maximum exposure.

3- Community green coverage is a biometeorological skeleton (GreenSect) that can be also structured within each residential (clustered) group by further simulation assessments for the exact needed area using ENVI-met.

4- Urban trees LAI can be defined in terms of its peak time ground shadow instead of its leaves upper looking area to be distinguished for urban shading function.

5- Despite ENVI-met still in its progress phase, it proved an acceptable and comparable capability to simulate urban thermal environments in terms of only design scenario's comparisons due to the fixation of weather data input all simulation time at the boundary conditions and the uncalculated wall's heat storage.

6- This study has revealed a new simple data extraction tool to be applied along with ENVI-met model. As the model area entered to ENVI-met was limited by the obtained satellite data, PolygonPlus; a simple visual basic code was designed to help extracting output data for a specific polygon from the simulated area. By this way, output for all grids simulated can be averaged to represent the whole local scale climate rather than to measure for a single or even several street canyons to draw a local climate picture for a neighbourhood.

It might need to be developed to calculate minimum and maximum values of the averaged metrology to offer a refined understanding of the local climate conditions.

7- Eventually, extracted data has been used methodologically for only one summer representative day to coupling outdoor-indoor weather data regardless that ENVI-met generated meteorology is generally cannot be compared with real measured data. ENVI-met generated meteorology is gathered within an Egyptian Typical Meteorological Year (EPW) file in order to relate indoor thermal performance with local urban details rather than to study indoors depending on a free horizon measurements at open site weather station. By this way, future development of ENV-met can make a unique weather data generator based on the fine and exact urban site details.

8- Theoretical regression model, URPLA, has been contributed to offer a comfort based land use parameters specification by urban planners for mid-latitudes. This is considered an initial research step towards easing and relating urban climate knowledge with urban planning and urban form design. More developments are expected as ENVI-met itself develops and as more simulation samples are examined. It will be available then to either predict the land use parameters for a neighbourhood in the future considering climate change aspects simply by using morphed meteorology generator as presented at the last paragraph of section 5.5.3.

9- The necessity of integrating the many interdisciplinary fields related to this research show the necessity of integrating the methodology and sub-methodologies used in the climate based structuring of urban form even on an educational and institutional basis not only for research purposes. None of the three suggested master plans could have been processed without such integration.

6.2 Recommendations:

1- Climate based neighbourhood urban planning, could be applied for urban – rural developments in at least Greater Cairo as it consumes about 30% of property investments in Egypt. Moreover, existing and ongoing urban developments can be reconsidered in the light of the research findings by urban regeneration policy either by land use filling or by urban and architectural redesign. Hence, population density can be controlled in the light of a long run projected population growth to sustainably benefiting a regional and national housing strategy rather than applying a constructional policy which has been referred to by Andres Duany as a solid protocols applied by the urban development community.

2- An establishment for the practitional and educational background of the importance of numerical simulations to the field of urban planning is needed due to the complexity and the wide range of research fields and urban environment elements involved at local climate scale. This is in order to relate passive design and climate knowledge to the real practice and improve its sustainability rather than building sprawled communities only to accommodate people. Nevertheless, the Egyptian urban planning law that still in its infancy stage as it is not related to the applied development projects or the housing strategy needs to consider this new approach for neighbourhood planning.

3- Urban trees used in landscape planning as one of the many elements involved in numerical simulations have to be measured and recorded in terms of its LAD and LAI to allow thermal performance assessment. Moreover, extended research have to take place from agricultural point of view to investigate the suitable grass or ground green coverage for the GreenSect nodes in arid circumstances in terms of the limited water sources, increased soil salts and hot climate specially for the rural developments were sandy salty soil is the dominant.

4- The research recommends using ENVI-met especially after its expected development to version 4.0 for sustainable urban development as it has proven a considerable capability to assessment of neighbourhood urban planning and form design in this thesis.

5- In completion to involving urban climate knowledge in the urban planning process, single building passive and sustainable design knowledge along with indoor simulation models and packages have to be involved efficiently within the construction and urban planning legislations and management especially in climatically classifying the patterns to divide a mega city such as greater Cairo into climate based zones. In this respect, the compactness degree as a form adaptor can be same time population controller.

6.3 Responsibilities for recommendation application:

Basically, the radical and synoptic urban design, planning and development methodologies used in the Egyptian policy which applies a central management system doesn't consider the good involvement of all urban design and planning parties in the early preparation stages of constructing new communities such as the public. Moreover, as it is not strongly established on the expected population growth in addition to the lack in population control policies, almost all master plans for Cairo have been overwhelmed. Nationally, decentralizing preparation of local design alternatives' authorities along with municipalities' public participation can improve urban form significantly, this have been approved world wide specially if a country area like Egypt includes different climatic classification. Such mechanisms need a governmental political support and efforts to be represented in an applied legislative way. The governmental bodies that might give efforts for these mechanisms to take place legislatively are;

1- Ministry of Housing and Urban Development:
    a- Housing and Building Research Centre; to sponsor a research series for studying thermal comfort in the built environment outdoor-indoor spaces and to examine the better alternatives for housing and urban patterns' prototypes along with completion of the Egyptian Residential Energy Code in cooperation with the Ministry of Energy and Electricity.
    b- General Organization of Physical Planning and the Central Development Authority; to prepare legislative drafts for sustainable urban planning in the different Egyptian climatic zones with passive housing designs and a climate based cities' zoning to be included in (Law3 1982; Law106 1999).
2- Ministry of Culture, National Organization for Urban Harmony; to investigate urban context, spaces, places and scenes in the light of the generated urban sustainable patterns and fabric from 1a and 1b.
3- Central Agency for Public Mobilization and Statistics, CAPMAS; to prepare a projected (future estimated) population for the next century to be used for today and future changed climates' urban planning.

6.4 Future work

Author is willing to submit the following titles in the form of journal articles or conference papers as an extension for thesis findings:

1- As if Climate Mattered I: Passive Neighborhood Urban Planning in Cairo, Egypt.
2- As if Climate Mattered II: Cairo2050 Land Use Predictions Using URPLA Model.
3- Environmental Thermal Impact Assessment of Regenerated Urban Form in Sheffield.
4- Rice-straw Based Cement Brick Thermal Performance Analysis in Cairo, Egypt.
5- Climate Change Based Accreditation Upgrade for Present Day Master Plans by Urban Form Redesign.

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Appendix 1

Appendix 1: Briefing for thermal comfort indices

Appendix 1: Briefing for thermal comfort indices

	Index name	Brief
a- Meteorology parameters indices:		
1	Psychrometric chart (comfort tool)	A graphical tool for plotting meteorology and assigning comfort zones for different regions in terms of *DBT, WBT, RH, VP*,...etc (Givoni 1969).
2	Bioclimatic chart (comfort tool)	A graphical tool for plotting meteorology and assigning comfort zones for different regions (Olgyay 1963; Olgyay 1967).
3	Mahoney bioclimatic tables (comfort tool)	Mainly in tables to record meteorology, compare them and then give design recommendations (Koenigsberger et al. 1970).
4	Effective Temperature (ET)	It is presented in Monograms and represents the instantaneous thermal sensation estimated experimentally as a combination of T_a, *RH* and v, (ASHRAE 1981).
5	Comfort triangle	A graphical tool for evaluating temperature variations (Evans 2003; Evans 2007).
6	wind shell index, (WCI)	Combining *T*a and V for outdoor cold conditions, (Siple and Passel 1945; Osczevski and Bluestein 2005; Shitzer 2007).
7	Actual Sensation Vote (ASV)	It depends on the meteorological parameters of air temp., relative humidity, wind speed and global radiation (Nikolopoulou 2004).
b- heat balance indices:		
1- steady state indices:		
	Index name	Brief
	Fanger equation, (PMV)	PMV expresses comfort on a scale from -3 to+3 for an indoor balanced human heat balance, (Fanger 1972).
2- transient state based heat balance indices:		
a)	Index of thermal sensation ITS and TS, the thermal sensation index	It considers the human physiology to maintain thermal equilibrium by sweat secretion at sufficient rate to achieve cooling, but wasn't originally considering the radiation exchanges, and then modified for outdoors as Thermal Sensation Index, ITS (Givoni 1963; Givoni 1969; Givoni et al. 2003).
b)	Perceived temperature (PT), The new effective temperature (ET*), The Standard Effective Temperature (SET*), The Outdoor Standard Effective Temperature (OUT_SET*), Physiologically Equivalent Temperature (PET).	The thermo-physiological assessment is made for a standard male whom has varying clothing and activity or work within a standardized environment and depending on the base of PMV, based on a complete heat budget model describing the physiological processes that provide reference environment in which heat fluxes would be the same as in the actual environment. Mean radiant temperature is equal to air temperature and calm with varying wind speed from 0.1 m/s of the PET to 0.15 of the ET*, SET* and OUT_SET*, 50% RH with a temperature of 20 °C. The perceived temperature PT and PET are closely correlated with r = 0,995, (Jendritzky and Nübler 1981; Gagge et al. 1986; Mayer and Hoppe 1987; Hoppe 1999; Spagnolo and de Dear 2003; Ali-Toudert 2005; Monteiro and Alucci 2006).
c)	Outdoor PMV	On an 8-points scale, it considers the transient condition of the urban environment including short-wave radiations to account for pedestrian walking circumstances.
d)	Dynamic effective temperature index d(ET)	A dynamic thermo physiological assessment depending on two node model of core-skin temperatures of agents walking within environment (Bruse 2005a; Bruse 2005b).

Appendix 2

Western and Socialist Urbanism comparison

Appendix 2: Western and Socialist Urbanism comparison, and continued tracking for the emergence of the urban planning and design

CIAM	***Basic features***	***Socialist***	***Basic features***
1-Lassaraz 1928	*The creation of urbanism field itself regarding the modernity in planning new communities after the satellite garden city and the British town planning act in 1909.*	*1929*	*Early 1929 delivered massive industrialization and urbanization regarding social equity in terms of housing, socialist towns dissolute into landscapes*
2- Frankfurt 1929	*Continued confronts between German Socialist and the French Liberalist to define directions of city planning.*	*1935*	*Debate about Moscow plan made the centralized policy is the socialist way of urbanization depending on the neighbourhood model*
3-Brussels 1930	*Functional city of Le-Corbusier.*	*1947*	*The Stalinist system of urbanization is the common concerning central city with medium rise buildings and a great industrial zones*
4- Athens 1933	*Le Corbusier manifesto recommendations for functional city planning, high ways and perpendicular networks, high rise blocks of buildings and great area for gardens, Character in practice for city zoning. New confronts between ASCORAL group and MARS group.*	*1950*	*A delegation from Germany to the Soviet union back to Berlin with a 16 Charta principals for urbanism focusing on the city centres, limitation of private properties, traffic, hypertrophied growth of cities and limitation of single family housing. Compactness to save area is a main feature with the classical monumental style. Orders from conference party of soviet union and similar parties in East European countries were the motivations for urbanization in CEE.*
5- Paris 1937	*Under German occupation*	*1955*	*Decrease of socialist urbanization in CEE.*
6- Bridgewater 1947	*MARS ascending Leadership, creation of physical environment, the introduction MODULAR and GRID for architectural standardization and architectural graphics.*	*1962*	*By this year, number of socialist cities were constructed like; Nova Huta, Poland; Dunaujvaros, Hungary; Dimitrovgrad, Bulgaria; and, Eisenhüttenstadt East Germany, depending the steel and Petrochemical industries..*
7- Bergamo 1949	*Character of human habitat, Le Corbusier ideas of three human establishments supporting city planning which are; agriculture, industry, exchange of national plans.*	*1967*	*Green separation between industrial zone and the residential zone as an environmental aspect but decline due to massive and heavy industrial constructions was notably one of the reasons of socialist model failure*

CIAM	*Basic features*	*Socialist*	*Basic features*
8-1951	*Renewing social heart of the city after industrial occupation, the visual art of urbanism, employment of contemporary expressionism in architecture and urban where it was the first time to gather urbanism to planning.*	*1970*	*The central pattern type of planning and planning policy was the reason of urban rural immigration towards cities' centres except some country towns like Schwedt in East Germany.*
9-AixenProvence 1953	*Continued confronts between ASCROL and MARS*	*1975*	*Urban suburbs huge constructions while centres declination in East Berlin, and Budapest(Ladd 2001; Noody 2004).*
10- Otterlo 1959	*The decay of CIAM whilst the principals of post modernism couldn't deny any of the functionalism but just giving dynamics in networks forms to cities and maintaining the patterns by development.*	*1989*	*Extensive urbanization for industrial suburbs revealed in a dramatic declination for the cities central neighbourhoods.*

11- Modern Architecture Research Group MARS   *Post Socialist Urban Planning*

12- City planning expression has emerged from Jane Jacob's writings against mega constructions and urban renewal projects in the great American cities

13- City design expression has emerged in the writings of Kevin Lynch, (Lynch 1960).

14- From 1940s till late 1960s, at least in the USA, due to the great population growth, the term urban design used instead of civic design or city design as the name of the field, (Schurch and 1999). Where confronts between the renewal and reconstruction trends with the city planning and urban design methodologies took place.

Appendix 3

URSULA initial report

Environmental thermal impact assessment of regenerated urban form

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Urban comfort is becoming an increasingly important issue due to climate change, increasing population and urbanisation. The greater use of mechanical cooling is not a reasonable long term solution as it will not only discharge more anthropogenic heat into the built environment but will also add to CO_2 emissions. It is therefore essential to ensure the built form does not significantly increase urban discomfort. As part of the EPSRC funded project Urban River Corridors and Sustainable Living Agendas, two urban regeneration alternatives for an existing site in Sheffield have been designed and micro climatically analysed based on a variety of design drivers which revealed radically different urban forms. The first, designed around access to the river, has urban streets running perpendicular to the river bank planted with street trees. The second design, developed to allow space for the river to flood into incorporates a grass channel through the centre of the site. Simulations for the two alternatives using extreme summer day weather in Sheffield was carried out using the numerical microclimate model ENVI-met BETA4 to assess the impact of these forms on the local climate. The simulations were used to compare air temperature Ta, wind speeds V, wind directions, relative humidity RH and the pedestrian comfort levels in terms of the Predicted Mean Vote (PMV) between the two designs. Four snapshot receptors were located to record Ta, RH, and V, and PMV at 1.5m above ground level. In comparison to receptors' output, an averaging methodology is used to describe the same parameters for the whole local climate of the regenerated urban area. Good agreement appeared between records from the individual receptors and the averaged values for Ta and RH, whereas considerable difference was found between the receptors and the average value for V and PMV, demonstrating a microclimate manipulation on the local scale. Regardless the close PMV trend of both alternatives' averaged values; increasing green coverage in the park option showed a minor urban thermal mass effect represented by a difference in PMV of 0.1-0.3 at peak time almost with no urban time lag. Two of the four receptors' showed similar PMV outputs of about 0.2 with 2h of urban time lag. These results provide insight into the microclimate effects of very different urban designs in a temperate climate zone like Sheffield.

Keywords: Average local meteorology, Urban thermal mass, Urban time lag, sustainable regeneration, urban forms

Appendix 4

Selected publications from thesis work

307; Passive design for urban thermal comfort: a comparison between different urban forms in Cairo, Egypt

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Abstract

In order to achieve outdoor thermal comfort in hot, arid zones it is necessary to have a clear understanding of the interactions between the prevailing climate and the urban form. Modern urban planning in Cairo does not use the vernacular urban principles or architectural forms, choosing instead a hybrid urban form between the Arab vernacular compact urban architecture and the western suburban dot pattern urban form could enhance the situation. This study investigated the microclimatic thermal behaviour of hybrid traditional and modern street canyon types of urban form in Cairo in order to establish an urban planning tool for passive cooling. Numerical simulations were performed, using both thermal and CFD software, for a hot summer's day in Cairo for different street canyon configurations including different canyon orientations to the prevailing wind and different canyon geometries. Initial results indicate that very dense urban layouts can have a beneficial impact upon outdoor thermal comfort but can, if incorrectly orientated, severely reduce the potential for any wind-driven cooling because of excessive wind sheltering. Some urban layout combinations of canyon geometry and orientation are suggested to provide satisfactory outdoor thermal comfort conditions at street level.

Keywords: urban planning, thermal comfort, ENVI-met, Cairo

1. Introduction

Urban planning can have a significant impact upon the thermal microclimate experienced in outdoor spaces. As urban populations and urban developments continue to grow, a planning strategy that attempts to improve outdoor thermal comfort has several benefits. Firstly, upward temperature trends due to climate change will need to be ameliorated to allow people to move around urban areas. Secondly, a cooler outside will help lessen the thermal stress on internal building conditions. Finally, a cooler city centre will help reduce urban heat island (UHI) effects at a city and regional level. Urban thermal microclimates are characterised in terms of wind speed and direction, mean radiant temperature, air temperature and relative humidity [1]. The key planning parameters influencing this microclimate are building fabric and density, street canyon geometry and orientation [2,3,4,5]. In hot, dry climates, these elements must be planned to avoid excessive heat stress. Moreover, as there still a lack in investigating urban planning alternatives for sake of comfort, [6,7], this paper examines how effective manipulating these parameters in establishing urban comfort levels.

Cairo has been chosen as the site for this study because of its rapid growth, hot climate and range of urban planning developments. Cairo is located at 30° 7'N and 31° 23'E. Its population around 16 million people and its rate of expansion over the last 30 years has overwhelmed the master plans developed for the city in 1970, 1982 and 1992.

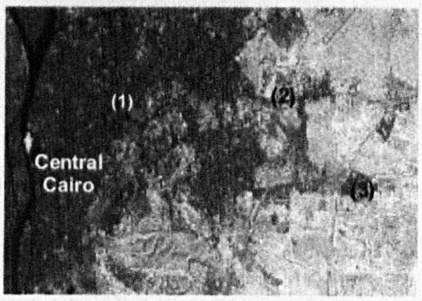

Fig. 1. Location of sites used in study

Different types of urban patterns have been developed as the city sprawled eastwards into the desert and three different urban patterns are analysed in this study – a high density city centre layout, a lower density suburban plan and a dot or single dwellings arrangement. Locations of these sites, shown as 1, 2 and 3 in Fig. 1. Cairo's climate is classified by ASHRAE [8] as mixed dry, semiarid. Based on 30 years of WMO Station no.623660 records at Cairo international airport the extreme hot week period typically lies between 26th June and 2nd July, with a maximum average outdoor air temperature of T_a = 44.0°C and a maximum average summer relative humidity of between 42% and 49% at midday. The maximum average June / July wind speed is 3.5 m/s between from a predominantly NW through to NE direction. The maximum average monthly global radiation levels are 7316 and 6893 Wh/m^2 for June and July respectively.

2. Sites description

2.1 Urban patterns

The 1st urban pattern (shown as 1 in Fig. 1) is high density, compact, multi family, low income apartment housing with a ground floor and four other floors in the central urban area north east to metropolitan Cairo that forms part of the Hadaek Al-Koba district. Fig. 2 shows the urban layout.

Fig. 2. Urban layout at Location 1

The 2nd urban pattern (shown as 2 in Fig. 1) is a mixed clustered-dot, multi family, high income apartments with a ground and three other floors, located in Sheraton Heliopolis urban area of metropolitan Cairo as part of the Misr Al-Gadida district (see Fig. 4).

Fig. 3. Urban layout at Location 2

The 3rd urban pattern (shown as 3 in Fig. 1) is a dot single and multi family, high income villas and apartments with a ground floor and 3 other floors located in the suburban are of metropolitan Cairo outside the first ring road of greater Cairo as part of new Cairo town (see Fig. 4). Table 1 gives some data on the three sites, as they are not equal in area.

3. Methodology

Thermal comfort assessments for the three urban layouts were performed using ENVI-met. It is a three-dimensional microclimate model that can simulate the surface-plant-air interactions within urban environments with a typical resolution of 0.5 to 10 m in space and 10 sec in time. ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics

Table 1: Details of the three sites (A_u is the total urban area of the site, A_g is the ground floor area of all the buildings on the site, C_p is the site construction percentage, C_d is the site construction density ratio and P_d is the site population density ratio for site urban area.

Site	A_u (m^2)	A_g (m^2)	C_p (A_g/A_u)	C_d (A_g/A_u)*no. Of floors	P_d (p/m^2)
1	5621	3839	0.683	3.415	0.758
2	41199	22082	0.536	2.144	0.046
3	62612	21075	0.337	1.008	0.030

Fig. 4. Urban layout at Location 3

and thermodynamics. The model includes the simulation of flow around and between buildings and the exchange processes of heat and vapour at the ground surface and at walls. ENVI-met is a Freeware program and is under constant development [9]. Outdoor thermal comfort is presented in this paper by the modified Predicted Mean Vote (PMV) at 1.2m a.g.l. PMV predicts the average thermal response (on a scale ranging from 'very hot' to 'very cold') of a group of people exposed to a set of environmental conditions such as air temperature, humidity and wind speed. PMV is calculated in ENVI-met by solving the modified Fanger equation developed by Jendritzky and Nubler, [10], for outdoor conditions, shown in the following eqn.:

$$M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} + S = 0$$

Where:

M is metabolic rate.

W is mechanical power

Q^* is the radiation budget (a function of mean radiant temperature T_{mrt} and air velocity v)

Q_H is turbulent flux of sensible heat (a function of air temperature T_a and v).

Q_L is turbulent flux of latent heat (diffused water vapour).

Q_{SW} is turbulent flux of latent heat (sweat evaporation).
Q_{Re} is respiratory heat flux (sensible and latent).
S is heat stored.

The mean radiant temperature is calculated in ENVI-met good approximation as mentioned in [11] and that cope with the work of Thorsson et al [12] and the heat balance equation for a surface in an urban canyon which is solved using the work of Kurn et al [13]. The final parameters are the sky view factor (SVF), representing the urban compactness, and the radiant temperature, representing the net radiation received by a human body with an absorption coefficient around 0.7 and an emissivity value of approximately 0.97. The receptor positions chosen for the ENVI-met analysis for each of the three sites are shown in Figs. 5, 6 and 7.

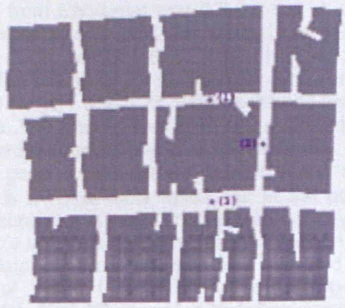

Fig. 5. Receptor positions for Location 1

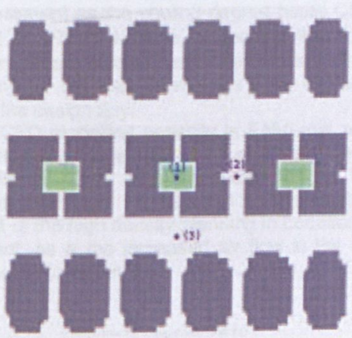

Fig. 6. Receptor positions for Location 2

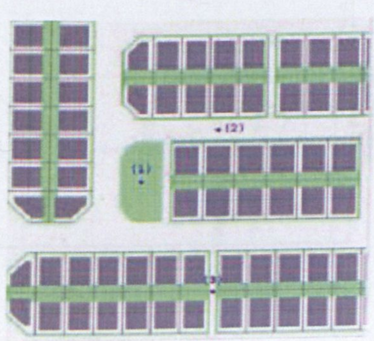

Fig. 7. Receptor positions for Location 3

Building materials defined in ENVI-met were constant in all three cases in order to allow only urban form based comparison whilst in good approximation with [14] and [15], for their average properties. As they are built up light grey cement tiled concrete roofs and light grey mortar finished brick walls in the three cases, U and albedo values used in simulations are as following;

U value Walls [W/m²K]	= 1.70
U value Roofs [W/m²K]	= 2.20
Albedo of Walls	= 0.30
Albedo of Roofs	= 0.15

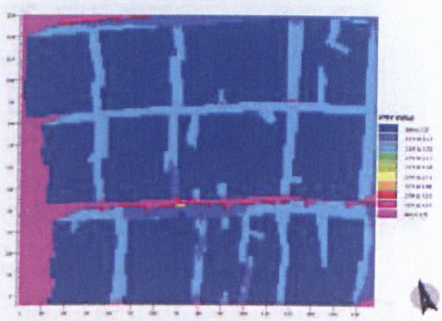

Fig. 8. Outdoor PMV mapping for Location 1, 12.00

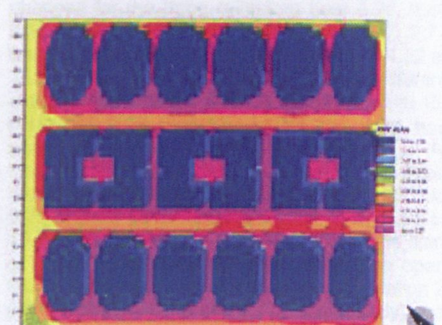

Fig. 9. Outdoor PMV mapping for Location 2, 12.00

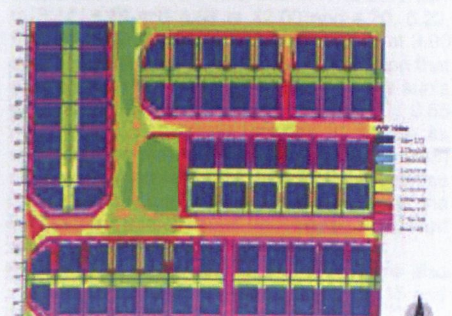

Fig. 10. Outdoor PMV mapping for Location 3, 12.00

4. Results analysis

Simulations were held for three one hour periods at hours - 9.00, 12.00, and 15.00 LST for the hottest period of the year in Cairo (late June/early July). Only the building fabric and green surfaces were modelled for these simulations (no urban trees were modelled) so that only the effect of different pattern forms on the urban canyons' temporal heating regime and comfort levels would be investigated. Figs. 8, 9 and 10 show the site mapping for outdoor PMV for Locations 1, 2 and 3 respectively at 12.00 LST, where the darkest shades represent the lowest PMV values (below 2.34) and the lightest the highest values (above 4.07).

In order to establish that the ENVI-met PMV values were reasonable a validation exercise was undertaken using the Ecotect psychrometric tool [16]. The thermal comfort and weather output data from ENVI-met was 0.5-0.6 Clo, a walking speed of 1.1m/s, 80% RH, wind speed 1.91 m/s and a T_{mrt} of 339.85K. The ENVI-met PMV comfort prediction for the receptor 3 in Location 2 at 11.00 LST was 6.73, which is beyond the PMV scale. The Ecotect tool produced a similarly very hot rating comfort level of 6.60 PMV value, which is in good agreement with the ENVI-met result. This is a remarkable result, but at this point of measurement is black asphalt with no shade on Cairo's hottest day which has been chosen to be simulated as most summer time is implied to be out of comfort in reference to meteorology calculated by [6], it was a research interest to have an idea about its maximum comfort assessment as the cooling degree hours CDH is 1658 at 27° C in June, supposing that further urban climate studies can achieve more effective cooling for the less stress days if the critical day was the design day.

The CFD modelling capacity in ENVI-met allows street level wind speeds to be modelled, and the results for 12.00 LST are shown for the three Locations in Figs. 11, 12 and 13. The sheltering effect of the high density planning in Location 1 is evident, as is the increased air flow in the open spaces at Location 3.

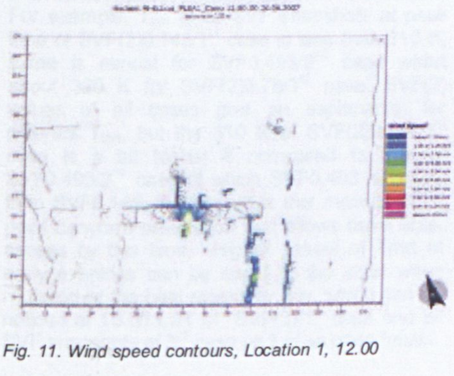

Fig. 11. Wind speed contours, Location 1, 12.00

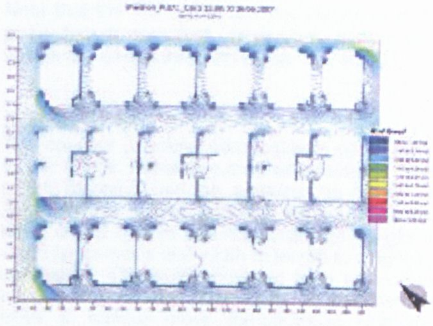

Fig. 12. Wind speed contours, Location 2, 12.00

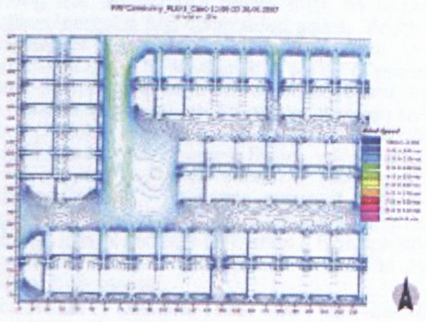

Fig. 13. Wind speed contours, Location 3, 12.00

At Location 1 the PMV was found to have changed for the three receptors from 3.96, 2.66 and 3.96 respectively at 9.00 LST to 2.77, 2.77 and 2.37 at 12.00 LST and 4.22, 2.49 and 4.22 at 15.00 LST. The variations arise from different exposures to direct solar radiation (SVF=0.15, 0.15 and 0.23 respectively) as the wind has almost no access to the site to decrease T_{mrt}. At Location 2 the PMV had changed for the three receptors from 6.31, 6.75, 6.01 at 9.00 LST to 5.20, 5.37, 4.54 at 12.00 and 2.38, 2.38, 4.51 at 15.00 LST. Those high values of PMV at the start of the day then decreasing are due to the open fabric of the three receptor positions of Location 2 (SVF of 0.546, 0.493 and 0.712 respectively) and the sheltering in some of the spaces from air flow. At Location 3 the PMV changed for the three snapshots from 4.19, 5.29 and 5.41 at 9.00 LST to 3.34, 4.08 and 4.69 at 12.00 and 4.20, 5.23, 5.40 at 15.00. Those high values of PMV at 9.00 and 12.00 are due to the canyons orientation that allowed maximum heat gain caused by the sun's position (SVF of 0.85, 0.78 and 0.65 respectively). At receptor position 3, despite its sheltering feature, the confinement (SVF= 0.65) did not allow adequate air movement to release heat stored, convicted and radiated from the lower street levels, hence causing the increased afternoon perception of thermal discomfort.

Relationships between T_{mrt} and SVF were also examined; results are shown in Figs. 14, 15 and 16.

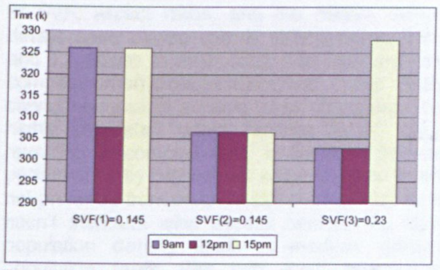

Fig. 14. Relationship between T_{mrt} and SVF and at the three receptors shown in Fig. 5 for Location 1

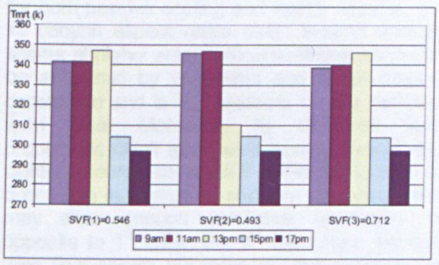

Fig. 15. Relationship between T_{mrt} and SVF and at the three receptors shown in Fig. 6 for Location 2

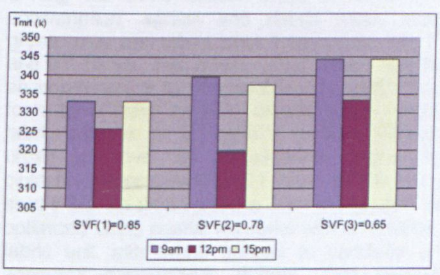

Fig. 16. Relationship between T_{mrt} and SVF and at the three receptors shown in Fig. 7 for Location 3

T_{mrt} has been measured as a biometeorological representation of the all net wave solar radiation of all 6directions from both hemi spheres that access urban spaces and cause radiant exchanges around human body. Consequently, it is a representation of urban fabric compactness. For example, T_{mrt} at all SVF snapshots at peak time of SVF(2)0.145/1st case is less than 310 K, same is almost for SVF0.493/2nd case whilst about 320 K for SVF(2)0.78/3rd case. SVF(2) values of all cases give an explanation for different T_{mrt}, but the 310 K of SVF(2)0.145/1st case is a bit higher if compared to that of SVF0.493/2nd case of which SVF0.493 is bigger than SVF0.145, the reason is this measurement point canyon's orientation that allows more solar access by this time. Higher values of Tmrt at early evenings can be owed to the short wave radiation of the heat stored by day, which can be noticed at 15.00 LST of SVF(3)/1st case and all SVF snapshots of 3rd case as it is an open fabric.

Note that the T_{mrt} scales are not the same in the three figures and that, in general, higher SVF values are associated with higher T_{mrt} values.

5. Discussion

The concept of urban compactness owes much to the Arabic Saharan urban architecture. This urban planning can be analysed in terms of, firstly, narrow spaces with high aspect ratios and small urban spaces between buildings, height to width for canyons and width to length to height for courtyards. Clustered courtyard form with urban spaces and network that could be confined by trees to replace more compactness help can guide wind and at the same time protect pedestrians within a series of local urban spaces using fine architectural details such as arched alleys, pergolas and colonnaded aisles. Another aspect is the delivery of people from one sheltered space to another via a series of spaces that attempt to ensure microclimate control; the urban consequence are for spaces that can help in controlling the SVF and hence reduce the direct heat gain, radiant fluxes within urban canyons and the whole pattern of the canyon's thermal regime. This was apparent from the close PMV and T_{mrt} values of Location 1 at most places except at 12.00 LST when a high sun and southerly azimuth allowed solar access to the lower main canyon.

In terms of outdoor PMV the high density Location 1 (featured in compactness as traditional Arab urban planning) performed best for the first half of the day but could then not easily dissipate its stored heat in the afternoon due to very low wind speeds. The urban layout for Location 2 in this study can be considered a hybrid urban form between the Arabic vernacular compact urban architecture and the western suburban dot or linear pattern urban form as it has the most recognized Arabic fabric form, the cluster which is a bigger scale of courtyards in medieval Arabic cities. This arrangement performed worst for the first half of the day because of air movement limitations due to the bad closure ratio (H/W/L), and only showed benefits from mid afternoon (where it outperformed the high density layout) when some shading and porosity to air flow combined to cool the urban canyons down. The western style layout of Location 3, perhaps surprisingly, performed generally better than the hybrid arrangement due to an isolated wind flow profile, [6], but only until mid afternoon when the sun could readily irradiate and warm the west and south facing canyons walls. It is apparent from the PMV analysis that the complex interactions between form, density and orientation is leading to a medium density population fabric to reveal in adjusted compactness degree.

6. Conclusion

The transient conditions of urban climate aren't completely controllable rather to be enhanced; all of the three cases are out of comfort levels (if acclimatization hasn't been counted). The compactness of each urban pattern case in terms of SVF, aspect ratios, and the pattern design details have played role in differentiating PMV and T_{mrt} values in each case. The high and low compact urban designs examined in this study cannot necessarily achieve these objectives. The highly populated urban housing in 1st case revealing in compact form is better in thermal performance by day but not same by night whilst not preferred from urban health point of view as it hasn't sufficient wind access besides the high population density itself. A medium density population fabric that can produce medium aspect ratios and medium SVF values can experience enough wind speed and solar access for both passive cooling and health aspects, but its canyon aspect ratios didn't support enough shelter at higher solar vertical positions which can be enhanced by vegetation and urban trees if considered and is not available for the compact form also. Moreover, its clustered form proportions didn't allow wind access through the cluster's courtyards which if studied in addition to orientation in relation to northern prevailing wind may allow enough ventilative alleviation. In opposite to 1st case, the 3rd case have enough wind flow access but more incident surfaces for direct radiation with a lower population density among the three cases, which is more land consumption, sprawl and needs much more green cover and urban trees if compared with 1st and 2nd cases. The urban hybrid cluster can be an improvement for the traditional Arabic urban form by utilizing medium density court yarded fabric such as in 2nd case to achieve suitable urban site over all compactness degree by clusters closure ratio (H/W/L). After all, this study shows that an urban passive form design can be optimized using spatial networks with orientation, fabric unit with urban spaces to conclude an adequate compactness degree upon specific housing and population providing shelter while allowing wind flow access for urban spaces cooling which can be called a hybrid urban form.

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On the development of an urban passive thermal comfort system in Cairo, Egypt

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ABSTRACT

This paper investigates how urban form can be designed to act as a passive thermal comfort system in Cairo. The system utilizes two main elements, the urban fabric form, with its green structure, and thermal comfort adaptation by introducing urban green scene stimulation with the time of exposure to the urban environment. The courtyard form on a large scale is used to study comfort levels, the effect of compactness on solar access and the local radiant heat island potential in a theoretical neighborhood design using a medium population housing concept as required by Egyptian urban planning laws. Urban canyons in a grid network, with three mid latitude orientations 15°, 45° and 75° from the E–W axis, were examined, with one canyon having virtually no shade. Other canyons had a green structure containing two types of native Egyptian trees. Numerical simulations using ENVI-met were performed for hot climate conditions. Although some very hot conditions were recorded, there were evident examples of more acceptable comfort levels and cooling potential for some orientations and degrees of urban compactness due to the clustered form with green cool islands and wind flow through the main canyons. Some design guidance on how to form urban passive cooling systems is presented.

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1. Introduction

1.1. Urban fabric form and the Egyptian urban planning laws

Urban development and planning laws in Egypt have made significant progress in the last 30 years, despite master plans often being overwhelmed during this period by several factors. One such factor is urban population density, which has a role in affecting urban comfort levels via the choice of urban fabric. An open or dot fabric allows winds to flow well but also creates high solar heat gains. A very compact form provides solar shading but minimizes wind flows for urban health and social purposes [1,2]. Urban physical form can be classified into two groups based on either the fabric form or the network form. They are the key elements related to controlling the outdoor thermal environments, comfort provision and urban heat island (UHI) mitigation, [3] and others. However, Ali-Toudert [4] said that "with respect to planning, studies directly focusing on the consequences of urban design strategies on comfort are dramatically lacking". Some recent comfort studies for a limited range of urban spaces have been presented by Bruse [5,6], and few neighborhood scale wind regime investigations have been reported by Hussein and Lee [7] and Kubota et al. [8]. Although there is no universal solution for climatic urban planning [9], for hot, dry climates the traditional courtyard and cluster are perceived as a successful form due its innovative climatic response [10] and its intelligent urban form [11]. Shashua-Bar and Hoffman [12] studied urban streets and courtyards with trees and achieved cooling effects of around 4.5 °C by the CTTC model. Waziry [13] studied courtyards in Fatimid Cairo and found that a courtyard axis orientated 60° from North was optimum for summer cooling and winter heating whilst an orientation of 70–90° from North was optimum for the low latitude location of Toshky in Egypt (latitude 22° 45′N). This second finding is in good agreement with Bourbia and Awbi [14], who concluded that "under low latitude conditions deviation of the street from E–W orientation may often be a desirable criterion in urban design". Muhaisen [15] concluded that in Cairo a courtyard having a perimeter to height ratio of 5, a width to length ratio of 0.5 and its long axis orientated 60° from East–West position would tend to have optimum summer shading and winter irradiance, which means not only the orientation is critical but also the courtyard closure ratio. Waziry [13] also investigated the courtyard closure ratio, C_a, defined as;

$$C_a = A_W/A_g \tag{1}$$

Where A_w is the area of the courtyard interior walls and A_g is the area of the courtyard ground floor. Furthermore, canyon

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asymmetries, vertical properties, aspect ratio, orientation, shading effects and irradiated surface area are features that control canyon thermal behavior [16], meaning that a certain degree of compactness in certain city zone can control the total heat exchange regime of the whole pattern. Duany [17] introduced the Transect as an urban planning tool for classifying the city, but did not demonstrate how traditional neighborhood developments can address different climates. Oke [18] presented a classification system for a city's urban form from a climatology point of view but did not specify how climate spatial parameters of the urban form can benefit in urban planning and communities development. An intermediate aspect between urban planning statistics and climate conditions is the population densities that decide fabric compactness. Literature defines urban canyons for microclimate studies by their geometrical cross-section height to width dimensions the aspect ratio H/W, and also by its sky view factor (SVF).

In this paper, in order to study local climate comfort for urban planning land use purposes at a neighborhood scale, a simple parameter, the compactness degree, Dc, is used to define the overall degree of compactness of an urban site and is obtained empirically from:

$$\begin{aligned} \mathrm{Dc} = {} & \text{Total local urban construction percentage} \\ & \times \text{Average number of floors of the local canopy layer} \\ & - A_g \times A_z \end{aligned} \tag{2}$$

The reason for having such factor is that the local climate studies do not parameterize the differentiated built up area and height of the whole urban site, which cannot rely only on either the SVF (it represents a specific point), or the aspect ratio H/W, which represents only a specific cross-section in a single canyon. The compactness degree factor represents both the urban ground floor constructed area (or the land bearing capacity for built area) and the local canopy layer height Zh in terms of the average number of floors. For example, the first case in Fahmy and Sharples [19] had a Dc of $0.683 \times 5 = 3.415$, that means if Dc equals average dominant number of floors in a built up urban area, the compactness degree is maximum for this local urban area and vice versa. Eventually, Dc could be classified into 5 classes to stand for city form classification into 5 circles (city centre = very compact, central urban = compact, general urban = medium, suburban = open, and rural urban = very open), regardless of urban network type. Hence, by controlling Dc, it can be said that the whole local scale built up area and height is controlled which in turn mean on a hand certain level of solar access and comfort and on the other hand means definite population.

1.2. Urban green structure

Urban planning theories are citing and stating that each urban planning community has to have its public green and vegetated land use area. The scale of parks and gardens is related to the planning communities' scales, Oke [20], i.e. cities have to have parks whilst each group of buildings has to have gardens to introduce a green nodes network all over the urban planning community. The need for urban trees integrated within the fabric as cooling elements is not doubted [21,22]. Matsuoka and Kaplan [23] discussed people's needs in landscape and found that they required contact with nature, aesthetic preference, recreation and play, green colors in terms of green areas all of which trees can provide. Huang et al. [24] modeled the summer cooling effect of trees in some American cities and found that huge reductions in mechanical cooling demands could be achieved by tree shading, with the reduction maximized upon an increase in tree coverage, especially if applied on an urban scale where wind speeds can show reductions due to canopy density not the canopy height. Whilst shading effect comparison between canopy height and radius at specific year time showed maximum shading effect by height, [25]. Eventually, an accurate selection and arrangement of a tree foliage should not decrease urban canyon wind speeds rather than to guide, and produce adequate shading effect.

Cooling is maximized due to the evapotranspiration actions that contribute to the water vapor whilst wind speed is catalyzing evaporation from the tree–soil system, [26]. Evapotranspiration of a plant can be calculated as following:

$$\mathrm{ETc} = \mathrm{Kc} \cdot \mathrm{ET}_0 \tag{3}$$

ETc is the evapotranspiration of a crop c.
Kc is the crop coefficient.
ET_0 is the potential evapotranspiration of vegetation derived.
I is the incident solar radiation upon crop.
a is the crop or vegetation Albedo.

1.3. Adaptive design of local scale

Field measurements of thermal comfort by many researchers around the world showed that the theoretical physical heat balance model of human thermal comfort cannot be relied on when studying the human thermal behavior in real buildings, [27]. This is especially true in urban spaces and in arid or humid climatic regions. The adaptive model reflects a give and take relationship between the environment and the user, [28]. The understanding that urban design and planning details support climate sensitive planning and design has been widely acknowledged and the realization of what the physical environmental adjustments can do for people and influence their comfort perception is being growing, [29]. Adaptation cannot be measured but just noticed, recorded and optimally designed because it is a human self action to improve comfort conditions and to make a reduction in thermal sensation and energy consumption. Brager and de Dear [28] defined adaptation from two points of view. First, physical adaptation for behavioral adjustments, that is concerning personal behavior, built environment design adjustments and cultural habits. Second, the physiological acclimatization or adaptation, which is a human response to the repeated circumstances. Nikolopoulou and Streemers [30] defined it in six points revealed from field surveys as Naturalness, Expectations, Experience, Time of exposure, Perceived control, and Environmental Stimulation.

Time of exposure is discussed in this paper in terms of optimizations between form compactness and orientation to increase shaded areas not in terms of calculating the time of exposure itself. However, this parameter can be calculated by assuming an optimal shaded path so that the exposed distances in this path can be used with the human walking speed to calculate the time. By this, an adaptive quantification can be used for neighborhood urban planning, but this is beyond the scope of this paper.

2. Methodology

2.1. Parameterization

In order to find out how urban passive systems can work within local urban fabrics two case sets located in Cairo (latitude 30° 7′ N, longitude 31° 23′ E) of different compactness degrees and population statistics were numerically simulated. Simulations were made by ENVI-met for 6 h from 10.00 to 16.00 LST (GMT + 3) for

Fig. 1. GIS 3-D modeling built over a Quick Bird 2008 satellite digitized image for the existing situation of the 3rd district (neighborhood in scale of about 1 km^2 area), 5th community, New Cairo.

a theoretically designed clustered urban fabric unit following Fahmy and Sharples [19] with a basic neighborhood grid network form in all alternatives studied. Meteorological input is based on 30 years of WMO Station no. 623660 records at Cairo international airport, [31]. The extreme hot week period typically lays between 26th June and 2nd July and simulations were held for the 26th of June, the extreme hot day of Cairo's summer, analyzed by ECO-TECT5.5, and selected as a simulation day to study the maximum outdoor thermal perception.

Thermal comfort depends partly on the radiant exchanges represented in the mean radiant temperature, *Tmrt*, which is dependent on global radiation and, in turn depends upon the fabric compactness. Snapshot receptors were placed to record the *Tmrt* with wind flow speed and its corresponding PMV value for comfort assessment at each point at 1.20 m a.g.l.

Nine snapshots were located at the middle of each canyon, distributed along two sections to contribute to records of two aspects. From green to non-green canyons, right to left of the symmetry axis and in–out cluster. Distances were about 25 m between each two points of the horizontal and vertical sections. Point place selection criteria were to lie in squares or in between canyon buildings of the irradiated avenue and along the cluster axe towards the green canyon. Simply, the idea is to apply parallel clustered avenue canyons (in real practice they could be unparallel or organic). One of them is almost shaded and vegetated and the other is not, so that a cooling potential due to fabric form and network orientation can take place towards the middle confined un-shaded canyon if existed.

As the objective was to measure the effect of fabric form and the green structure of the site on the urban site passive cooling, PMV was calculated by ENVI-met for outdoor conditions, and the thermal comfort criteria assessment within urban spaces assumed a human walking speed of 1.1 m/s, 0.5 Clo, Ta of 312 K, RH of 50% and wind speed at 10 m height a.g.l of 3.5 m/s. *Tmrt* is a biometeorological representation of the all net wave solar radiation that access urban spaces from all six directions of both hemispheres and cause radiant exchanges around human body, due to fabric compactness, and an indication about the influence of the fabric plus urban trees used to provide shelter.

To measure the cooling effect in combination with the fabric solar access effect of the proposed parallel avenue forms and due to ENVI-met global radiation over estimation at morning, under estimation at nights, (Ali-Toudert [4], estimated a 0.84 adjustment factor of global radiation calculated by ENVI-met to equal measurements in hot regions and overestimations because of not calculating soil evaporative cooling [32]), *Tmrt* intensity has been calculated as the difference between *Tmrt* at the start and end point of each cross-section that is referred to as local urban radiant heat island caused by the fabric compactness, LUHI.

Table 1
Housing design and land use statistics.

Name of design alternative	Urban site total area in feddans	Green coverage percentage	Cluster closure ratio	Cluster aspect ratio; H/W/L	Total urban construction percentage	Average no. of site floors	Degree of compactness	Max. no. of families	Total population	Population/feddans	Law no.3
1 Set1_Dc1	51.07	0.251	0.494	13/50/200	21.8	3.875	0.844	1120	4200	82.24	100–150 person/ feddans
2 Set1_Dc2	51.07		0.608	16/50/200	21.8	4.750	1.036	1408	5280	103.38	
3 Set2_Dc1	37.24	0.183	0.515	13/42/180	26.5	3.923	1.040	1144	4290	115.20	
4 Set2_Dc2	37.24		0.635	16/42/180	26.5	4.923	1.302	1236	4635	124.46	
5 Set2_Dc3	37.24		0.754	19/42/180	28.0	5.846	1.549	1424	5340	143.39	

No. of families is calculated upon subtracting ground floor dwellings of the main middle avenue from residential use to be as commercial and recreational uses that support mixed use concept at night after losing heat by nocturnal cooling. Family no. of flats is also calculated as 150 m^2/flat/family.
Facilities buildings at service civic centre are 10 m in all design sets and 13 m in Set2_Dc2 to increase the compactness degree without increasing site population assuming that more facilities are needed.
The actual residential land use can be calculated after extracting 33% for the network and green coverage as (Law3 1982) tells, also after extracting the civic buildings areas, hence the residential land use for example for Set2_Dc3 is 23.707 feddans is 63.66% of site area, i.e. the actual constructed area which is 10.428 feddans gives construction percentage of 43.99%.
Refer to eq. no. (1) for cluster closure ratio.
Feddan = 4200 m^2.

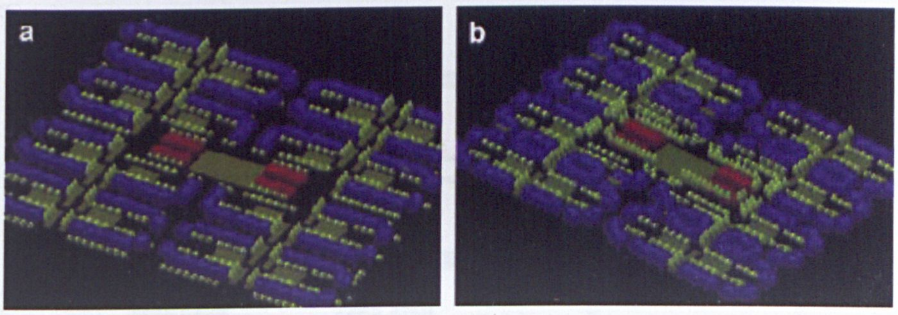

Fig. 2. (a,b): CAD illustrations for design sets; 1 to the left and 2 is right.

More or less LUHI intensity means disturbed cooling effect at points of the section whilst meaning also irregular compactness degree towards the reference point. According to Shashua-Bar and Hoffman [33] criteria, reference point should be in sunshine most of the day and within 100 m as an intermediate microclimate background, in this study, a reference point for the local scale in the irradiated avenue canyon was chosen which is no.1 for both cross-sections to measure LUHI towards the open SVF green measuring point at the civic garden (snapshot no.9). It has been used also to measuring LUHI towards the green shaded point in the pedestrian green avenue canyon at snapshot no.4.

LUHI (4-1) and LUHI (9-1) are within 125 m distance as local climate distance can be up to 1000 m. Orientations were 15°, 45°, 75°, that means no. of simulations were 15 each took about 4 days to simulate 6 h of solar movement on 26th of June.

Building materials defined in ENVI-met were constant in all three cases in order to allow only urban form based comparison whilst in good approximation with Oke [34], for their average properties.

The U and Albedo values used in simulations are as follows:

U value of walls = 1.70
U value of roofs = 2.20
Albedo of walls = 0.25
Albedo of roofs = 0.15

2.2. Site planning, fabric and housing design

Cairo had mainly three master plans for urban developments in the second half of the last century, in 1970, 1982 and 1992 [35]. The actual planning physical conditions of site in this paper, Fig. 1, can be described as neighborhood dot pattern single family villa housing; which is the common feature of New Cairo, the extension of Cairo to the east due to urban development plan of 1982 and its modifications in 1992. This is not only unlike the heritage background of housing and patterns types in historical Cairo, but also unlike the early 20th century urban developments to the North–East. The cultural, environmental and religious requirements of social coherence, privacy and climate control guided patterns forms towards compactness. Indeed, the compactness is decreased towards the rural zones of the city, but the western type of dot fabric urban planning even in the neighborhood form of New Cairo is not a solution of such rapid growth in Cairo, [36]. Consequently, these communities converted into urban sprawls which increased the problem of Greater Cairo in addition to environmental sustainability problems. These patterns are completely depending on indoor mechanical cooling and cannot close to urban comfort as well, the relation between urban form design; its urban comfort levels and the indoor comfort levels has been approved, [24].

Hence, climate knowledge applications have been used to design a theoretical passive medium population fabric in order to avoid extra solar access of open fabric as well as to avoid less air quality of compact fabric. To study the idea of parallel shaded un-shaded avenue clustered canyons in making the local scale form as part of an urban passive system, the simulated theoretical designs depended on the urban cluster as fabric unit. Urban network is simple gird for basic neighborhood design, the fabric form has followed some urban principles such as spatial unity (for example, fabric bay and courtyards sizing in a repetitive order but with caution of monotony), network axial planning, continuity with

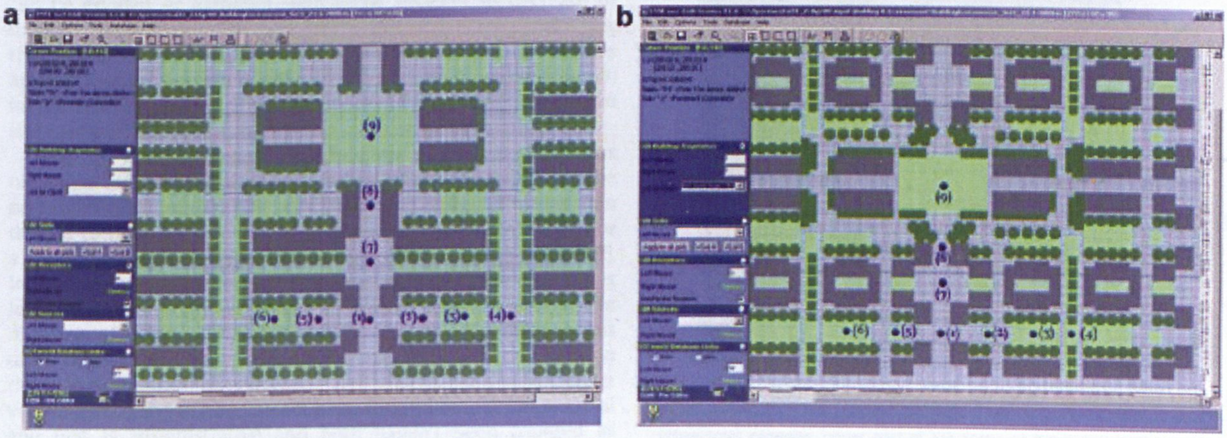

Fig. 3. (a,b): Snapshot receptor positions for design sets; 1 to the left and 2 is right.

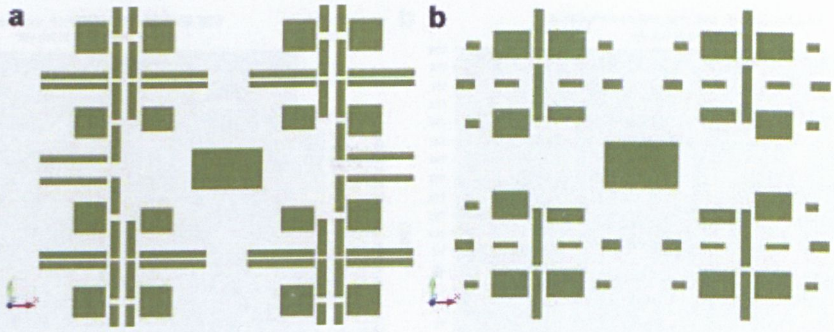

Fig. 4. (a,b): The green structure of both designs sets 1 and 2.

some openings between linear fabric to limit street length and support pedestrian access through houses but again with caution to keeping privacy of each place for which clusters can do well, Moughtin [37] and others.

Function of streets was to make an avenue canyon green covered and shaded as a pedestrian axe linking houses clusters while a middle one is un-shaded axial avenue canyon for access towards the civic centre, the concept is to generate an overall cooling effect if possible at immediate surroundings as distance between avenues axes is 113 m of 95 m street length between avenues for both design sets following Shashua-Bar [33].

It is designed to cope with the Egyptian urban planning law [38] that tells a population of 100–150/feddan (feddan is an Egyptian area measuring unit = 4200 m^2) of medium housing. Also it states about 30% of urban site area as network, recreational and green coverage uses, but green coverage applied in this paper is larger, Table 1. Two sets have been designed to stand for sustainable form diversity, [39]. However, the linear fabric design sets have site areas of 51.07 and 37.24 feddans respectively. They have been generated into linear form to reduce land consumed and increase population. Also to allow high degree of controlling urban form and forming clusters to provide more shelter rather than the dot form that increase heat gain from 4 facades, [40]. Designed form can be classified between urban climate zones, UCZ2-3 for highly developed, medium density urban area on a 7 categories urban scale as described by Oke [18]. On the opposite 6 categories' scale from rural to city centre of Duany [17], the Transect, it is almost equal to slice, T4-5. Housing type used is the attached linear fabric multi family apartment buildings having module of 150 m^2 of total flat area that can be divided or gathered with more adjacent to decrease or increase the unit area. The population calculations are considering the Egyptian family of 3.75 people, based on the population studies and surveys for Egypt till 2006 done by CAPMAS [41]. Fig. 2(a,b) indicates a 3-D graphs for design sets, and Table 1 illustrates urban site configuration that supports the medium population.

First set has two design cases and set two has three. It was needed to add more compactness to one set of them to achieve the population limit of Law [38]. The 2nd set was chosen rather than the 1st to have a third case as it has more design details, hence a better thermal performance and comfort levels are expected, [42]. In order to study the effect of increasing site population on comfort levels, each set cases are similar in master plan but different in numbers of floors (G + 3) and (G + 4) and (G + 5) which means more families but doesn't exceed the 150 person/feddan limit. In the second and third compactness cases of Set2, the middle canyon venue is designed to have mixed uses. Ground floor is commercial and first is administrative and both haven't been counted as housing units. This is to cope with the increase in service facilities needed due to the increase in population of the added floor to increase the compactness degree of the site. Housing units are calculated as maximum; i.e. each family is accommodated in a 150 m^2. flat which suits a family of 4–5 persons. The urban cluster properties for the four compactness degrees are shown also in Table 1. Fig. 3(a,b) illustrate snapshot receptor positions for recording simulation output across the three avenues and along the main middle avenue.

2.3. The green structure

Fig. 4(a,b) illustrates the green structure used in the cases containing two types of native Egyptian trees. Both trees' types referred to as 20 m and 15 m dense distinct crown trees in ENVI-met plants database as assumption for foliage characteristics due to difficulties in field measurements for LAD, [43]. Distribution of trees in situ has three criteria, first to provide maximum sheltering from direct radiation to reducing heat gain and to minimize human time of exposure in completion with fabric. This has been done by sensitive linear trees' arrangements and placements in urban spaces. The 20 m evergreen for maximum shading of main green avenues at minimum VSA as its crown is rocket in shape, and 15 m semi evergreen for maximum shading at maximum VSA near buildings which is parabolic shaped crown. Second, this linear arrangement help

Fig. 5. Green urban scene: (1) the lower part by the red dotted line is the canyon flooring, (2) facades as middle part of urban scene, (3) green line defines green color of urban trees canopies, upper part of the scene or the canyon's ceiling. Broomhall, Sheffield, UK.

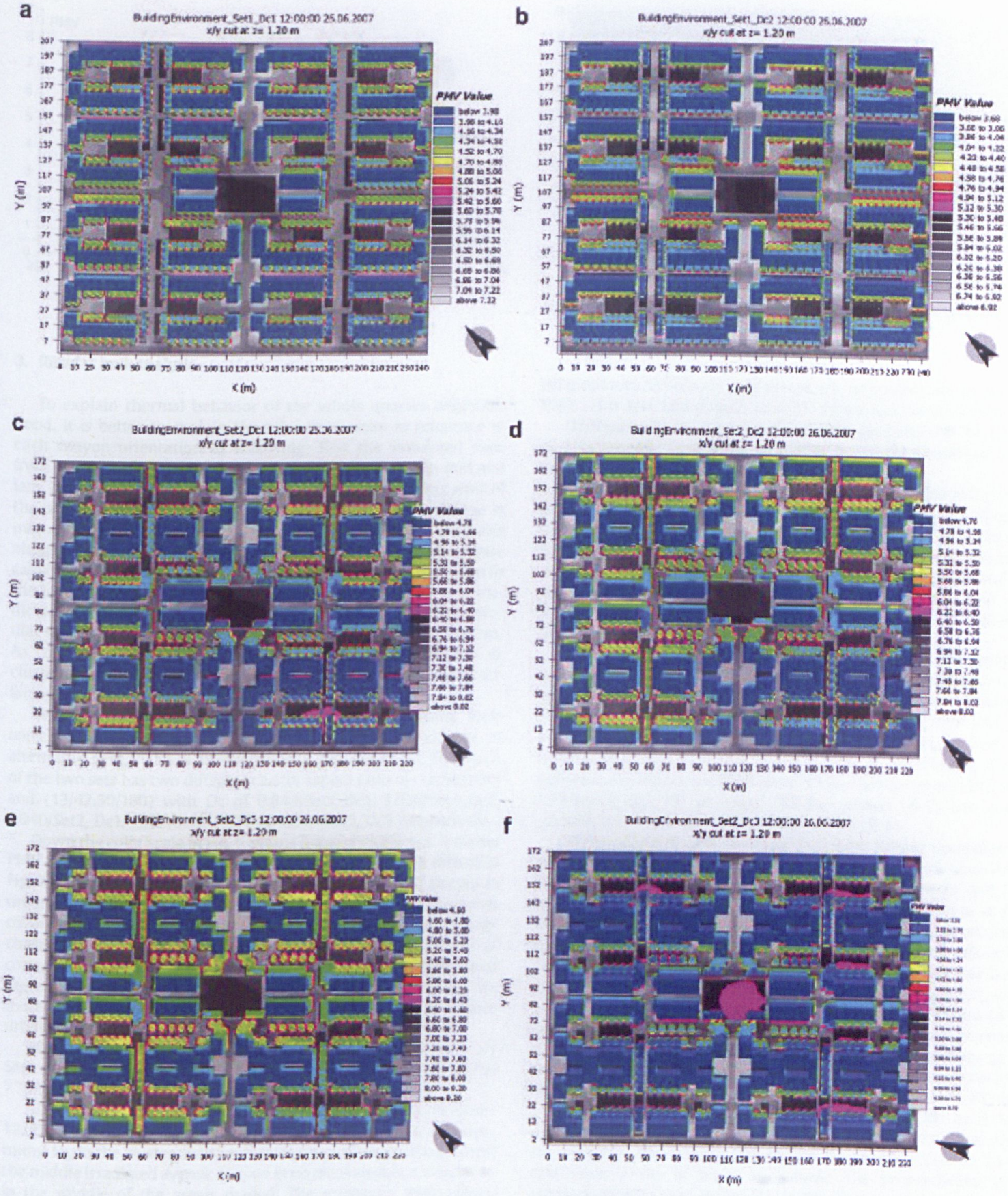

Fig. 6. (a,b): PMV mapping for Set1_Dc1 and Set1_Dc2 at 45° respectively, at 12.00 LST. (c,d): PMV mapping for Set2_Dc1 and Set2_Dc2 at 45° respectively, at 12.00 LST. (e,f): PMV mapping for Set2_Dc3 45° and 75° respectively, at 12.00 LST.

with the fabric form to maximize the guidance of wind flow to go across canyons and the cluster courtyards. Third, to achieve a minimum green color ratio of 33% for the urban scene at any place in the site that can be considered the ceiling of canyons formed by trees' crowns, Fig. 5 illustrate an example, to stimulate environment comfort adaptation. The green structure with trees as whole is increasing the degree of naturalness and people's perceived control.

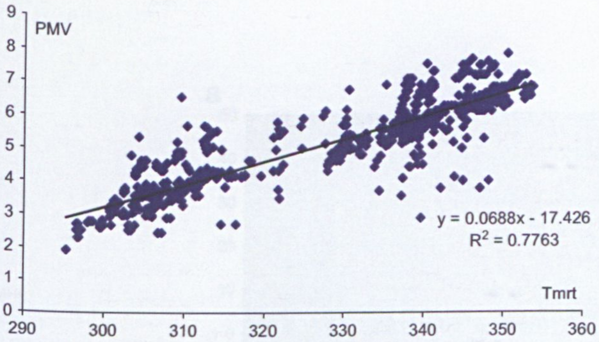

Fig. 7. PMV of all design sets' records.

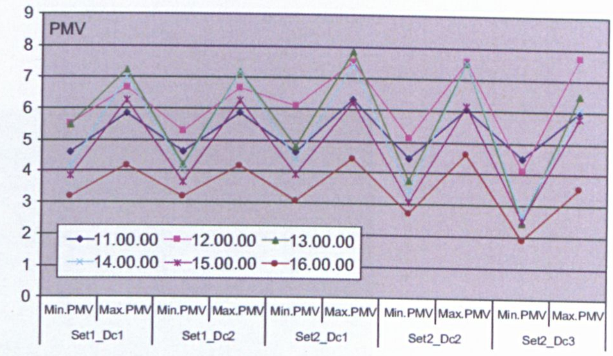

Fig. 8. Absolute PMV minimum and maximum for all set designs at all times measures.

3. Results and analysis

To explain thermal behavior of the whole quarter neighborhood, it is better to explain the solar movement in reference to each canyon orientation as following; first the simulated time from 10.00 to 16.00 LST is divided into 3 intervals, early, mid and late. For network orientation 15° the sun is almost facing axes of the main avenue canyons at early simulated time while oblique at mid and perpendicular late. For orientation 45° the sun is almost oblique then perpendicular and oblique again to the main avenue canyons, sun rise and set at 5.58 and 19.55 LST respectively. Sun in the last orientation is facing the cluster's main axes, i.e. perpendicular to the main avenue canyons, then oblique and perpendicular to the cluster's main axes, i.e. facing the main avenue canyons. As conclusion snapshots that lie on the axes either avenues or clusters will record higher *Tmrt* and PMV values at the time they are facing sun.

While fabric is formed to be linear attached housing with construction percentage of 22% of total neighborhood area of alternative Set1, 26.5% of alternative Set2 and 28% of Set_Dc3, each of the two sets has two different cluster aspect ratio of (13/50/200) and (13/42.50/180) with Dc of 0.844/Set1_Dc1, 1.036/Set1_Dc2, 1.040/Set2_Dc1, 1.302/Set2_Dc2 and 1.549/Set2_Dc3 respectively.

Down the color scale in Fig. 6 means hot and vice versa. It shows PMV records at 12.00 LST which had a regression of 0.78 shown in Fig. 7 when plotted against *Tmrt*. This can be explained simply as urban comfort expressed in PMV here is dependant on the green coverage area, number of urban trees, its geometries and foliage characteristics, orientation of urban pattern and fabric degree of compactness which are all not represented in the concluded regression equation on the graph and draw the attention to the more needed formula that gather all these parameters in further urban climate planning studies.

PMV values vary from 3.21 to 7.21/Set1_Dc1, 3.2 to 7.17/ Set1_Dc2, 3.07 to 7.85/Set2_Dc1, 2.73 to 7.57/Set2_Dc2 and 1.90 to 7.70/Set2_Dc3 as minima's to maxim's respectively, Fig. 8.

All minimum vales are at 16.00 LST and all maximum are either 12.00 or 13.00 LST due to the solar altitude direct gain. All minimums lay in the cluster courtyards wings not off coarse those along the middle irradiated avenue canyon even not snapshot 4 which are in the middle of the green shaded. The minimum PMV values measured for a pattern orientation was 3.21/Set1_Dc1_45°, by increasing the compactness of this Set the minimum PMV inside clusters stayed around at 45° orientation, but by increasing compactness with land used built area and detailed design features of Set2, the minimum recorded PMV value moved to be 3.07 at Set2_Dc1_15° despite this case has solar gain in front of the three main avenue canyons then the minimum was 2.73 at Set2_Dc2_75°. All minimum records are at 16.00 LST, the no comparable minimum PMV value was 1.90 of Set2_Dc3_75° which has the maximum Dc.

LUHI intensity for the 1st and 2nd cross-section called (4-1) and (9-1) is presented in Fig. 9(a–c) against Dc for all orientations at all times of each Dc in order to study its behavior.

In Set1_Dc1, LUHI of section (4-1) was almost (+) due to high SVF of snapshots' points and wide canyon width (H/W = 0.62), despite some (−) values of Set1_Dc1_45° that reached −34.2° at 14.00 LST. Surprisingly, LUHI of (9-1) records was mostly (−) regardless of its open SVF of 0.91, the fluctuations of LUHI records gives an indication about the necessity to adjust the built up-vegetation land use percentages not only the increasing of compactness in terms of increased canopy layer height (no. of floors).

In Set2, almost all LUHI values in both sections were negative except when direct gain takes place due to canyon orientation with respect to solar position, the only (+) records were also in the 45° orientation. Moreover the vegetated surfaces of the right and left avenue canyons and higher wind speeds recorded in 15° and 75° orientations from E–W axe played a role in intercepting direct radiation and improving LUHI hence PMV. The maximum LUHI was −26.3/Set2_Dc2_75° at 13.00 LST for section (4-1) and about −8.9/Set2_Dc2_75° at 13.00 LST for section (9-1).

Design details of Set2_Dc3 maximized the shelter. Comparisons of LUHI in all cases show that preferability is for the orientations at 15° and 75 degrees as they display steady differences and (−) values more than of 45 which means more cooling effect or in fact less heating effect. This happened when the spatial grid structure of the quarter was almost parallel to the quarter prevailing inflow, i.e. either parallel or perpendicular to the avenue canyons, the basic network grid allowed wind diffusion. According to Fig. 9(b,c), with −8.4° and −8.7° LUHI is better at Set2_Dc3_15° for sections (4-1) and (9-1) as it is (−) and steady regardless of the maximum record of −26.7°/Set2_Dc3_75° and −9.3/Set2_Dc3_75° for sections (4-1) and (9-1) at 13.00 LST respectively. Same (−) and steady records were found also in Set2_Dc1_15°, Set2_Dc1_75°, Set2_Dc2_15° and Set2_Dc2_75°. But preferability goes to Set2_Dc3_15° as it had more population. Set2_Dc3_15° cannot be considered to contradict the preferred mid latitude orientation discussed in Section 1.1 of this paper rather to be in agreement. The perpendicular grid network clarifies that as the 15° of the main canyons from north equals 75° from north for the secondary canyons and for the main axis of all clusters, i.e. clusters' axes should have been perpendicular to the main parallel canyons as design and discussed previously.

After all, the higher rates of PMV at peak times specially in design set two behaved better due its fabric details expressed steady (−) LUHI records.

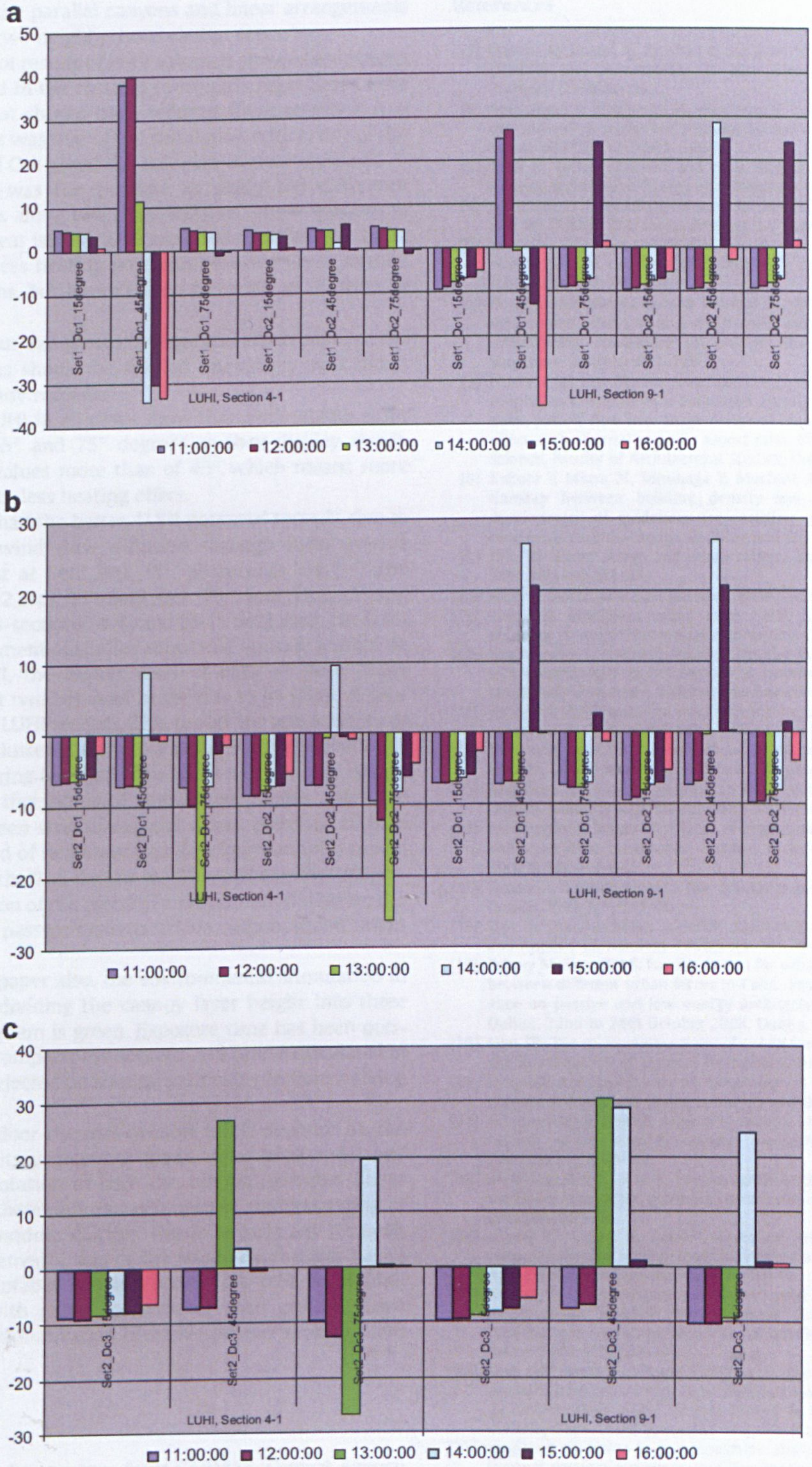

Fig. 9. (a): Set1 of all avenues' canyons Dc and orientations. (b). Set2 of all avenues' canyons Dc and orientations. (c): Set2_Dc3 of all orientations.

4. Conclusions

Studied in this paper, the idea of utilizing a medium population clustered form with the parallel canyons and linear arrangements of urban trees using two neighborhood design sets.

Despite the very hot results of PMV values, it showed reductions at snapshots enclosed in the clusters courtyards regardless of the low closure ratios that should have reduced these results if it is higher. Moreover, this was due to the simulation critical day of the hot arid conditions of Cairo, and the software overestimations.

The later reason was the purpose to study the difference between Tmrt records along two cross-sections. The (−) values of local urban radiant heat island, LUHI recorded contribute to more cooling potential or less heating potential between green shaded and irradiated canyons, but haven't been recorded at all times as expected.

The (+) values mean that green coverage and aspect ratios of the green avenue canyons should be studied intensively as it didn't help as showed in many records.

Comparisons of LUHI in all cases show that preferability is for the orientations at 15° and 75° degrees as they display steady differences and (−) values more than of 45° which means more cooling effect or in fact less heating effect.

Set2 design cases had the better, LUHI potential records, due to green cool islands, wind flow diffusion through form avenue canyons. LUHI is best at Set2_Dc3_15°, all records are (−) and steady, same as in Set2_Dc1_15°, Set2_Dc1_75°, Set2_Dc2_15° and Set2_Dc2_75° of cross-sections (4-1) and (9-1). Set2_Dc3_15° LUHI records were in agreement of studies about mid latitude preferable orientations. After all, the higher rates of PMV at peak times specially in design set two behaved better due to its fabric details expressed steady (−) LUHI records. This proofs the applicability of the parallel avenues clustered form to act climatically well, if Dc is to be studied considering local land use and housing needs design but with caution to thresholds of population. It also gives the approach towards green structuring and urban patterns' climate geometrification based of neighborhood development with mixed uses as illustrated in the 2nd design set. Thermal comfort adaptation was the completion of the physical environment design on the way of making urban passive systems within neighborhood urban planning process.

Quantified in this paper also, the environmental stimulation in the urban scene. By dividing the canopy layer height into three parts, at least one of them is green. Exposure time has been optimized by varieties of compactness degrees, and can be calculated in further studies for a selected pedestrian path using human walking speed.

Finally, where outdoor thermal comfort levels depends on the form design details, its vegetation; green cover area and trees' geometries then orientation of both the canyon axes and linear trees arrangements; there still an uncompleted understanding of how to control that outdoor climate, this is beyond any research capabilities or achievements, any of the paper alternatives hasn't after all deliver acceptable comfort level. This tells to rethink more confinement with green roofs rather than ground green coverage and how acclimatization of native people enables them to bear?

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DUAL STAGE SIMULATIONS TO STUDY THE MICROCLIMATIC EFFECTS OF TREES ON THERMAL COMFORT IN A RESIDENTIAL BUILDING, CAIRO, EGYPT

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ABSTRACT

This paper describes an outdoor-indoor thermal investigation of a multifamily residential building during summer in Cairo, Egypt.

Initially, microclimate meteorological data was generated for an urban settlement with and without trees being incorporated in to the development. The software ENVI-met was used for this first stage. Two kinds of tree planting (15m high Ficus Elastica and 20m Yellow Poinciana) were simulated, together with the existing scenario that has no trees.

Next, the energy analysis package DesignBuilder used the modified microclimate data from ENVI-met to simulate indoor comfort levels in the residences. The Predicted Mean Vote (PMV) was used to quantify thermal comfort. The study found that the best indoor comfort levels were achieved using the 15m high Ficus Elastica trees in the urban site. The main conclusion from this investigation is that new urban developments in Cairo shouldn't only consider trees planting at the planning stage, but also a specific type should be used for better outdoor-indoor performance. Moreover, results indicate that raw weather data files used without microclimate physical adjustments are not adequate for detailed comfort analysis and indoor-outdoor simulations should be coupled for better representing indoor climate.

Key words: ENVI-met, Design Builder, Urban trees, PMV, Microclimate, Solar radiation.

INTRODUCTION

Urban climatology has been a growing field of research over the last few decades (Arnfield 2003). Urban vegetation influences urban climate and hence pedestrian comfort levels along with indoor ones (Dimoudi and Nikolopoulou 2003; DOE 1995; Oke et al. 1989). Urban tress not only help to control heat gain and mitigate urban heat islands, (Huang et al. 2008; Taha 1997), but also reduce noise levels (Gidlof-Gunnarsson and Ohrstrom 2007; Lam et al. 2005). The effect of urban climate on the indoor environment is, potentially, to reduce heat gains and buildings energy demands (Akbari 2002; Givoni 1998; Huang et al. 1987). Despite different trees' foliage differentiate solar access to its environment, (Kotzen 2003; Kumar and Kaushik 2005), there still a lack in supplying climate knowledge to improve design, (Oke 2006). Furthermore, while indoor comfort and energy simulation packages are used increasingly (Jentsch et al. 2008), today, more than 30 years went since the sustainable development concept was firstly launched in the 1970s (Brundtland 1989), indoor simulations still tend to be isolated from an important element affecting urban microclimate, such as urban trees. Apart from urban trees, there is a good understanding and establishment in literature that urban form, land use, presence of natural geographical structures, urban / rural settings etc, are all affect microclimate, (Ali-Toudert 2005; Fahmy and Sharples 2008c; Fahmy and Sharples 2009a; Givoni 1998; Swaid 1992).

Urban trees thermal behaviour advantages and disadvantages are also well established, (Oke et al. 1989). Urban trees main advantage as a bioclimatic responsive design element is to produce shadow whereas its main disadvantages is blocking wind, (Yoshida et al. 2006). Urban canyons and spaces thermal behaviour at micro and local scales differ from city centres to suburban and onward to rural and open areas, (Oke 2006). According to (ASHRAE 2005) the accuracy of weather data files used in building simulation design packages depends on the site typology, its landscape, the method of meteorology measurements and the time period of years for the statistically generated data (Radhi 2009). The compiled weather data derived from open-air measurements above and outside the urban canopy layer does not represent the micro scale details of urban sites within the canopy layer. In addition, packages cannot allow for the effects of specific urban trees types - for example, the different leaf area densities and evapotranspiration rates of urban trees that influence solar access and heat exchanges if planted around buildings.

Urban trees examined to study if (i) the use of raw weather data file without micro-local effects is satisfactory and (ii) if an urban site such as that examined performs better with or without trees and with which kind of urban trees is most effective. Consequently, a pre-design stage has to be considered to generate the influence of actual urban details on the data compiled within weather files.

Urban simulations were performed using ENVI-met, which results were simulated within Design Builder to assess indoor comfort levels. ENVI-met is a 3-D CFD numerical model that is capable of simulating complete built environment surface-air-plant thermal interactions based on the fluid dynamics and heat transfer fundamentals, (Bruse 2008). ENVI-met model is used in this study rather than for example the CTTC model introduced by (Swaid et al. 1993) regardless its improvements, (Shashua-Bar et al. 2004). Preference came from ENVI-met applies a soil-plant-air sub-model and its plants database that depend on the plant numerical physiological representation using height, Albedo, leaf area density, stomata resistance, etc in addition to the main model complete meteorological outputs. ENVI-met is professionally used in literature and validated for assessing built environment, (Ali-Toudert and Mayer 2007a, 2007b; Fahmy and Sharples 2008c; Fahmy and Sharples 2009a). In this paper it will be used as meteorology generator to assess effects of two trees for indoor analysis. Meteonorm, (METEONORM 2009; Radhi 2009), meteorological generator could have been used but again it will not stand for trees physiological effects. Indoor simulations were performed using Design Builder which is 3-D comprehensive interface built over the Energy Plus dynamic model that can simulate indoor thermal interactions, (DesignBuilder 2009).

SIMULATION METHODOLOGY

Building and Environment

The urban site studied in this paper is part of the second district in the fifth community, which lies in New Cairo just out the first ring road of Cairo. It is on a micro scale from the urban climate point of view and is located at 30° 18'N and 31° 63'E. New Cairo's climate is mixed dry, semiarid (ASHRAE 2005).
The simulated day of the first stage was the 7th June, which is in the middle of a typical summer week for Cairo. Meteorological entries were the statistical hourly data of June, table 1 illustrate main input data used in stage one. In fact, the specific day does not matter as the objective was to study the difference in indoor comfort levels produced due to urban details regardless the day. The New Cairo site currently has almost no trees; hence, the first stage model has been used in three situations. The first one without trees, the second using 20m high Yellow Poinciana trees and the third using 15m high Ficus Elastica trees (in addition to grass green converge).
The rooms examined were on the middle floor of a typical three-storey multifamily apartment block. It consists of two apartments on each floor with five people per family. The building has 3 floors each of them 3m height. Ground floor area is 300m2 where typical floors are 330m2. The northern and southern façades have about 11% glazing of their area for each whilst the western and eastern have about 5% for each. Figure 1 shows an aerial view of the site and the residential building used in the simulation.

Table 1: main input data used in stage one.

PARAMETER	VALUE
Ta, air dry bulb temperature	300.55° K
RH, relative humidity	51%
V, wind speed	3.5 m/s at 10m height
Soil temperature	299.25° K at 0-0.5m and 297.15° K at 0.5-2m
Soil humidity	70% at 0-0.5m and 80% at 0.5-2m depth
U value Walls	1.7
U value Roofs	2.2
Albedo Walls	0.25
Albedo Roofs	0.15
Albedo Pavement	0.40
Albedo trees & grass	0.20

Figure 1.a: 0.6m resolution Quick bird 2008 satellite image of the site and building examined in the study.

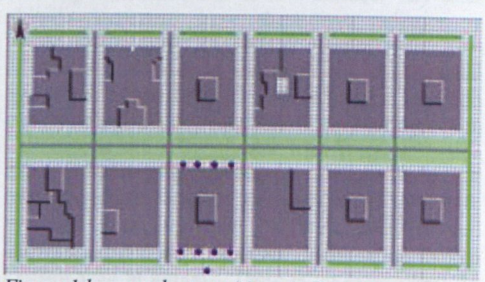

Figure 1.b: snapshots positions in Base case.

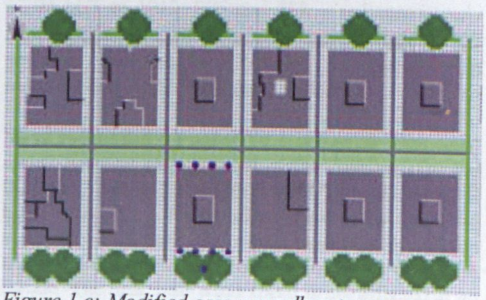

Figure 1.c: Modified case regardless tree type.

Trees modelling

Two trees are studied modify existing situation, the *Peltophorum Pterocarpum* (commercially Yellow Poinciana) and *Ficus Elastica* (commercially Indian Rubber Plant). Ficus Elastica is an evergreen dense tree with 12-15m mature height, and 4-6 trunk height. The Yellow Poinciana is a deciduous less dense tree that can reach up to 20m height and up to 6m trunk height, (Aiad 1999; USDA 2009). Trees were numerically modelled after (Lalic and Mihailovic 2004) to generate 10 values of trees' leaf area density, LAD. LAD, is the total leaves area in the unit volume of a tree horizontal slice, (Law et al. 2001b). Eventually, these 10 values needed by ENVI-met plants database were added to represent trees in simulations of the first stage.

Software cycling

As the main passive technique used is to produce shadows by applying urban trees, the built form stayed the same in all cases without modifications. This is to study only trees different foliage effects that are not considered by indoor simulation packages. The first simulation stage used ENVI-met 3.1 (Bruse 2008) to generate urban climate meteorology. This is to record the near-building meteorology, which in turn is affecting the indoor environment comfort levels and energy consumption. ENVI-met is capable of generating climate conditions at different heights; hence, the selected generated data from the snapshots was at 4.5m a.g.l. (above ground level), representing the middle height of the facade. Cairo has almost northern prevailing wind. Consequently, northern façade is expected to show higher speeds rather than the southern one. Moreover, as the southern façade receive the maximum radiation whilst northern facade receives minimum radiation, records were averaged from nine snapshot receptors. Eight of them at 0.5m away from the building and the last one under trees in front of the main façade, figure 1/b, c. In the second stage of the analysis, DesignBuilder 1.9 was used with these weather data in an EPW format to simulate each urban case effect on the indoor comfort level at this height. EnergyPlus3.0, (DOE 2009), was used to produce comma separated value (CSV) weather files from the widely used Typical Meteorological Year (TMY2) of the energy plus file (EPW) to write the ENVI-met output in and to modify the exact site coordinates. Eventually, the reverse cycle is done to convert the new data to EPW again. The generated data introduced to the original file was from 10.00-15.00 LST, local solar time (UTC+3). Generated meteorology in the first stage were the hourly means of dry bulb temperature, wet bulb temperature, relative humidity, global radiation, direct radiation, diffuse radiation and wind speed recorded from snapshots.

Indoor comfort assessment was made in terms of Fanger's Predicted mean Vote (PMV), (ISO7730 1984), which is calculated every 15 minutes. Comfort levels have been simulated for an original weather data file despite it uses hourly means of open-air measurements above canopy layer. While in this paper, the weather data produced are hourly means within canopy layer. To illustrate the effect of different vegetative details, the No Trees situation is considered the reference file to compare its PMV with that produced with 15m and 20m tree files.

RESULTS AND DISSCUTION

Comfort analysis

Weather data generated in the first stage using ENVI-met were very different from the original scenario, especially for the solar radiation. It is influenced by the trees' foliage and canopy characteristics. Radiation records were 0 w/m^2 from 16.00 LST onward regardless a reduction adjusting factor should be applied to the generated data [(Ali-Toudert 2005) used an adjustment factor of 0.84 for simulation overestimated outputs]. Solar adjustment factor is a value can be used to fit ENVI-met radiation values to observed values; it varies from 0.5-1.5 and should be applied in the input configuration file if a field measurement takes place. Figure 2 shows the three simulated and original solar radiation data. To assure this output was viable a sun path analysis using ECOTECT5.6, (AutoDesk 2008), was performed (see Figure 3) and showed the solar positions and radiation on the building facades. At early-simulated time, ENVI-met predicted reduced direct short-wave radiation levels compared to the original data due to the obstruction by buildings when sun was at low altitude. By solar altitude increases, more short-wave radiation is gained within site. By altitude decreases afternoon (13.00 LST), more short-wave radiation is obstructed again. The diffused radiation at all times is less than corresponding airport value due to the blockage from buildings at site. The shorter 15m Trees performed better in intercepting radiation as a whole trend. For example, global radiation values recorded were 948, 898 and 886 w/m^2 for NoTrees, 20mTree and 15mTree respectively whereas 1103 w/m2 is the measurement at airport. There is no explanation for the only discrepancy result of global radiation at 12.00 LST of 1012, 906 and 883 w/m^2 respectively in comparison to 888 w/m^2; it can be owed to the software overestimation, which is included in radiation and hence PMV results plotted.

Wind speeds did not exceed 0.1 m/s in all three cases due to the southerly position of the building plot and the trees, whilst the original wind data did not fall below 1.5 m/s. Explanation is owed to the wind angle of attack over the whole buildings group and the close distance of trees canopies to southern facade. The near wall wind speed is not affected at all with wind vortex if produced within urban canyon, as the southern façade and tree canopy are almost same body. The southern position of the building plot itself is responsible of that beside the close distance between each two back-to-back buildings. In addition to the different heights from measured at 10.0m to simulated at 4.5m.

As ENVI-met plant model is using a soil-plant-air sub-model, RH is increased within site environment due to the high soil water content used in the configuration input file. The applied water content is about triple the actual measured soil water content. In fact, specific water levels supplied means extra cost in real practice. The reason to increase soil water input is to suggest providing sufficient water by irrigation for trees evapotranspiration to take effect. Figures 4 and 5 show comparisons of air temperature (DBT) and relative humidity (RH) for the generated and the original file. As a result, the simulated environment is warmer and more humid due to the buildings and vegetation. This lead to increasing indoor PMV levels compared to those produced from the original raw weather files. Nevertheless, PMV values derived from generated files is different from each other and giving impression about different foliage effects. Moreover, the original file did not account for four aspects. First, the urban details around the building, i.e. the original data come from a weather station at an airport site that is in the open desert. Second, the original site location has nothing to do with the real urban location of the building, i.e. solar positions and radiations are different. Third, the measuring height of the original weather file is different from the generated one that is a representation for the whole building; i.e. 4.5m a.g.l. Fourth, the original data collected using meteorological instruments while the generated data simulated.

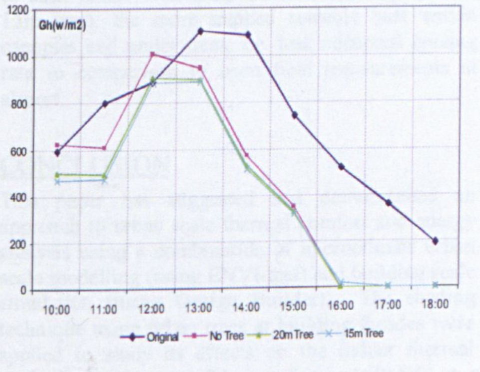

Figure 2: Global radiation generated compared with original.

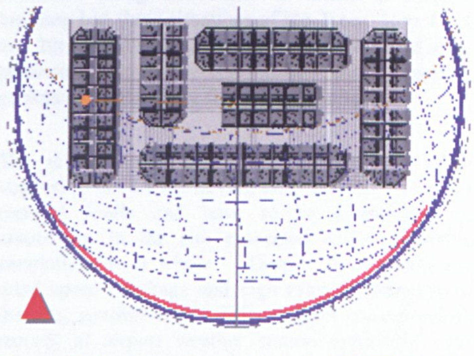

Figure. 3: Solar position analysis by ECOTECT 5.6.

Figure 4: RH generated compared with original.

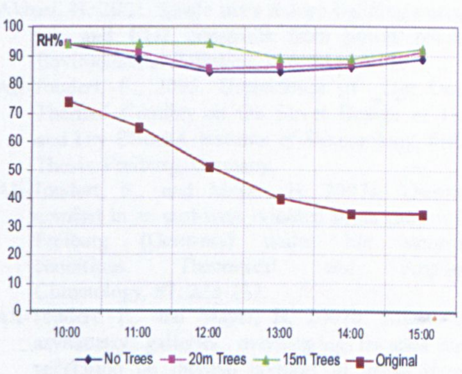

Figure 5: RH generated compared with original.

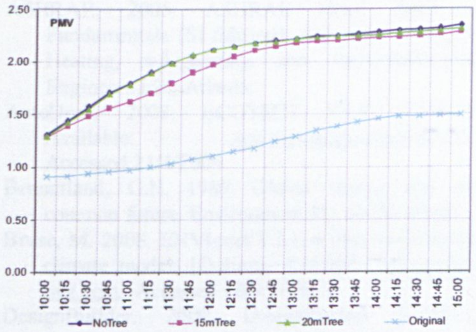

Figure 6: PMV generated compared with original.

PMV comfort assessments are presented in Figure 6. The upper curves are for the base and modified cases, the last curve is for PMV values generated from the original weather file. Results show differences between the 15m Trees situation and both No Trees and the 20m Trees from 10.30 to 12.45 LST.

PMV difference reached 0.2 from 11.00 to 12.00 LST, the better indoor comfort level achieved by using 15m Trees. PMV was calculated as 2.1 for No Trees and 20m Trees and 1.9 for 15m Trees at 11.45 LST. Differences then decrease to be 0.1 towards the end of the simulated time. The Ficus Elastica 15m trees showed better indoor comfort levels because this tree's foliage intercepted more solar radiation within its shadow area. The much reductions were before the sun zenith time at 13.00 LST at which the built environment and trees intercept more short-wave and sky long-wave radiations. After maximum solar height, direct and diffused radiations start to decrease. The less differences between comfort records occur afternoon where the sensible heat from ground and trapped by and under trees canopies affect the ambient conditions and close PMV records to each other. The more dense tree foliage (of the 15m tree), the more trapped sensible heat within canopies and under trees, i.e. less nocturnal cooling rate in comparison to open field measurements at airport.

CONCLUSION

This paper has suggested and demonstrated an approach to urban scale thermal comfort and energy analysis using a combination of microclimate urban scale modelling (using ENVI-met) and building scale simulation (using Design Builder). The shading technique using urban trees at building facades were applied to study its effects on the indoor thermal performance in terms of the comfort scale PMV.

As indoor thermal analysis packages don't stand for urban trees; its radiant interactions and evapotranspiration effects, dual stage outdoor-indoor simulations had to be held.

In the first stage, three urban situations have been simulated using ENVI-met in which a selected building had three situations of No Trees, 15m Trees and 20m Trees surrounding its facades. Second stage performed using DesignBuilder after compiling generated meteorology from the first stage.

The results from this study indicate that urban vegetation details are having crucial effect on indoor comfort levels and have to be considered for assessment in the site examined and in building simulations as a whole. Despite trees introduced wind speed blockage and high rates of humidity to the site, comfort levels differed from corresponding records at airport weather station especially until noon. Hence, raw data files are not adequate to be used directly with indoor thermal analysis packages for such as DesignBuilder, EnergyPlus and others. Moreover, the 15m tree Ficus Elastica tree showed less comfort levels rather than the 20m Yellow Poinciana tree when its effects have been introduced to the data file used for indoor comfort study. Consequently, it can be concluded that each tree type has its specific impact on the urban microclimate, indoor comfort and, in turn, on the energy demand could be needed for mechanical cooling. Eventually, specific trees types can be not only selected for its urban thermal behaviour but also for its better indoor impact. This draw attention and raises further approaches to investigate about simulation packages' accuracy and whether it need additional tools to account for real urban details, or to apply same methodology used in this paper.

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LAI based trees selection for mid latitude urban developments: A microclimatic study in Cairo, Egypt

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ABSTRACT

To study the leaf area index, LAI, based thermal performance in distinguishing trees for Cairo's urban developments, ENVI-met plants database was used as platform for a foliage modeling parameter, the leaf area density, LAD. Two Egyptian trees; *Ficus elastica*, and *Peltophorum pterocarpum* were simulated in 2 urban sites with one having no trees, whilst the second is having *Ficus nitida* trees. Trees LAD values were calculated using flat leaves' trees LAI definition to produce maximum ground solid shadow at peak time. An empirical value of 1 for LAI is applied to numerically introduce LAD values for ENVI-met.

Basically, different meteorological records showed improvements for pedestrian comfort and ambient microclimate of the building using *F. elastica*. About 40–50% interception of direct radiation, reductions in surfaces' fluxes around trees and in radiant temperature T_{mrt} in comparison to base cases gave preferability to *F. elastica*. The lack of soil water prevented evapotranspiration to take place effectively and the reduced wind speeds concluded negligible air temperature differences from both base cases except slightly appeared with the *F. elastica*. Results show that a flat leaves tree if does not validate LAI of 1, the ground shading would not fulfill about 50% direct radiation interception and this value can be used as a reference for urban trees selection.

Further simulations were held to investigate LAI value of maximum direct radiation interception.

Performing additional simulations, *F. elastica* of LAI of 3 intercepted almost 84% of direct radiation and revealed implications about urban trees in practice and its actual LAI.

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1. Introduction

1.1. Urban trees effects

As part of complete passive urban climate knowledge and in order to optimize urban form, urban trees as an important element of site vegetation have to lie in the core of any applied design procedure. Urban trees improve the microclimatic performance of built environment, adapt patterns to climate change and reduce energy consumptions [1–6]

Despite this is true, urban climate complexities prevented dedicating this knowledge towards supporting the decision of many interdisciplinary related fields, [5,7,8], such as landscape, urban planning and design which consider urban trees along with many other elements. Part of this complexity is the many mathematics, physics and models have been introduced to field to assess urban thermal interactions, but few were capable to assess human thermal comfort, all meteorological parameters and all urban surfaces and vegetation thermal interactions sufficiently [9–12]. Urban developments in Cairo were overwhelmed through the last couple of decades and did not consider urban trees to control its hot climate [13]. In a tree microclimate, as radiant interactions critically affect comfort assessment, mean radiant temperature has been considered by many studies to give an indication about pedestrian thermal comfort [11,14,15]. The mean radiant temperature T_{mrt} is defined as 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure' [16]. For buildings interior comfort and energy demands assessment, the mean ambient air temperature, T_a is used to assess the heat transfer from outside to inside buildings through walls by conduction.

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Tree microclimate is mainly due to radiation intercepted and evapotranspiration contributing to modifying the heat balance of surrounding environment. Radiation interception is owed to canopy prevention of short- and long-wave radiation from the upper hemisphere whereas evapotranspiration is owed to water content carrying capacity of the soil–tree–air system. Evaporation takes place from leaves surfaces to air [17], and transpiration from soil through leaves stems due to photosynthesis that circulates this system [18]. Eventually, the latent heat increases and the sensible heat decreases within a tree environment leading to lower, air temperature T_a [2]. Less heating rate for surrounding air is then achieved meaning better comfort levels outdoors as well as for indoors due to modifying ambient conditions [19]. Radiation balance that a tree modifies is expressed by the total budget firstly presented by Monteith [20] and represented perfectly in literature [21–23].

Oppositely, microclimate wind speed reduction is a fairly disadvantage for urban trees specially when gathered in groups due to the drag force of plant canopies [15–17] if compared to open land wind speeds [25,26]. Another disadvantage is the diurnal patterns of warmer nighttime temperatures and cooler daytime temperatures due to the trapped heat and humidity within urban canopy layer if also compared with the rapid nocturnal cooling of open areas [25].

Trees have a role in making visual perspective and environmental stimulation by increasing the green color in urban scene for psychological adaptation [27,28]. Urban trees improve outdoor spaces, place making and spatial format, order, harmony, contrast, scale, proportions and variety which all can be attributed to trees urban arrangements and its geometric characteristics [29,30]. Furthermore, trees are air filters, confidentiality elements [31] and noise reduction elements [32,33]. Nevertheless, urban trees have also more than the thermal benefits, Yoshida et al. [24] demonstrated that parks and vegetation have a magnificent role in increasing health quality.

1.2. Trees canopies

Selection of urban trees to accomplishing specific urban design criteria can be based on many aspects, such as its thermal performance which in turn depend on foliage characteristics as well as tree mature shape; i.e. total height and canopy geometry. In addition, botanical aspects decide selection of a tree to be planted in a specific site; i.e. type of soil to be planted in, tree deciduousness, depth and radius of roots, capability of bearing site hazards and harsh climates [29,30].

LAD and LAI are conceptual environmental canopy modeling parameters in studying trees' heat exchanges with environment as they have significant role in urban heat balances [34,35]. Based on the radiation interception concept through flat leaves trees' canopies, LAI is defined as a dimensionless value of the total upper leaves area of a tree divided by the tree planting ground area [34,36]. By definition, 100% of direct solar radiation interception means that canopy shadow should equal ground planting area. In this respect, LAI for same tree could vary from a season to another by deciduousness, from age to another by growth, and there still the chances to propose other definitions and interpretations of LAI [34]. This is why trees in this study will be modeled as if they are mature. LAD is key parameter needed to model the radiation through a tree canopy and between a tree and its environment. It can be defined as the total leaves area in the unit volume of a tree horizontal slices along the height of a tree that can give an idea about the vertical leaves distribution [37,38]. LAD modeling can be estimated by means of field measurements manually or using instrumentations along with empirical models [34]. For example, Meir et al. [37] investigated tropical trees estimations by a photographic method. Beer–Lambert law was used by Pierce and Running [39] to calculate LAI using the extinction coefficient and the measured light transmission. Stadt and Lieffers [40] described trees 3-D profiles, but for limited specimens and their MIXLIGHT model could be complicated in application. Lalic and Mihailovic [41] derived an empirical method to model LAD if the maximum LAD, L_m, is known which in turn is calculated in terms of LAI.

LAI can be measured, manually or by instruments, for example Kotzen [42] used a scanner for LAI measurements, whilst the Plant Canopy Analyzer (type Licor LAI-2000) and many ways are reported by others [34,36,40]. LAI investigations for trees modeling in hot regions have lacking studies either from a measurement point of view or from modeling point of view, may be Kotzen [42] study in arid regions and Shahidan et al. [36] study in hot humid region are few examples in comparison with other climate regions and forest trees studies [34,37,40]. In addition, urban trees modeling to assess their thermal effects in contact with buildings in hot regions are more lacking. Therefore, some questions can be raised here; how tree can be modeled without LAI or LAD sources for specific species even without measurement, how tree foliage can support its plantation preferability than another, and what is the preferred LAI of a tree to produce maximum shadow at peak hour of a mid latitude site?

2. Methodology

2.1. Method

As the main idea of this paper is to study how urban trees for specific locations can be, assessed and selected, foliage modeling is crucial. Trees' foliage thermal performance distinction while a complex vegetation interaction with built environment takes place is difficult to achieve due to the problematic and transient criteria of outdoors. Consequently, numerical simulations have been held to easily simulate such complexities using ENVI-met which helps providing design and planning decision support [9]. ENVI-met [43] is a three-dimensional numerical model that can simulate the surface–plant–air interactions of urban environments with a typical resolution of 0.5–10 m in space from a single building up to neighborhood provided 250 grids at maximum. ENVI-met is a non-hydrostatic prognostic model based on the fundamental laws of fluid dynamics and thermodynamics in a much improved package than only a CFD package for fluid dynamics' simulations [11]. It nearly has the complete capability to simulate built environments from microclimate scale to local climate scale at any location. This is regardless overestimations because of un-calculating soil heat storage [44] and global radiation overestimations by day and under estimations for the nocturnal cooling by night [22]. Moreover, the combination of biometeorological outputs of ENVI-met gives deep understanding of climate in the urban canopy layer, such as presented by Fahmy and Sharples [28].

ENVI-met vegetation model is formed over one-dimensional column with height z_p (z in Eqs. (D) and (E)) in which the profile of a tree LAD represent the amount and the distribution of leaves [43]. The distribution of roots within the soil system is represented by the root area density, RAD, from the surface towards the root depth – z_r. By this way all types of vegetation can be modeled. The vegetation model is formed of four sub-models; first is the turbulent fluxes of heat and vapor sub-model that solve interactions of temperature, humidity and air movement between air and tree foliage. Second solves interactions of evaporation and transpiration of water from soil through a plant that is affected with its stomata resistance r_s. Differing from grass to tall trees, it is simply the number of stomata of a plant green leaves per unit area that describe the resistance of transpired water can face to be evaporated through leaves. Hence, stomata resistance depends on short-wave radiation and the soil water. The third sub-model is a steady state leaf energy budget depending on the foliage Albedo, a_f and light transmission factor, tr_f, that control net short-wave radiation absorbed by plant. The fourth sub-model calculates mass of water transpired from soil depending on the soil hydraulic diffusivity through its layers, so that evapotranspiration effect can take place if stomata resistance and soil water allow that. Detailed information and equations can be found in Bruce [43].

The package has its own numerical database for some plants LAD profiles that is used when simulating the native environment of these plants and depends on analytical approaches that can help in obtaining the LAD distribution of other plants especially if the LAI is known [43]. This answers why ENVI-met has been decisively preferred to numerically simulate the new trees. As the foliage characteristics of hot climates' trees such as Egyptian trees investigated in this study are not represented in the plants data base of the software, the data base needed 10 LAD values to be distributed over the tree normalized height. Hence, the LAD values for 10 slices of each tree had to be generated to introduce these new trees to ENVI-met and to study their thermal performance foliage based differences.

2.2. Case studies

Cairo, latitude of 30°7′N and longitude of 31°23′E, is a semi-arid mid latitude climate zone [45]. The first case C1 is part of the Fifth community which is built in late 20th century, as one of New Cairo communities. It lies to the east of the 1st Greater Cairo's ring road.

However, the fabric surfaces of the detached housing dot pattern form mostly for single family and the lack of planned structure of vegetation increased urban canyons heat gain and thermal stress [13]. Table 1 shows abbreviations used in this study. Second case C2 is part of Misr Al-Gadida which was built starting from early 20th century until 1990s to the northeast of metropolitan Cairo as multi family housing [46]. C1 is having no trees, whilst C2 is already having almost the 4 m height *Ficus nitida* trees. That is why a second case is used in this study; to compare selected trees' performances, i.e. if there will be difference in tree type to be used in each urban site upon its details. Paving in both cases under trees is cement concrete tiles of 2.5 cm over sandy loam soil as described in ENVI-met finishing profiles which is in good agreement as real existing, finishing properties are mentioned in Table 2.

2.3. Tree description

Trees studied in this paper to replace the existing situation in each site are the *Peltophorum pterocarpum* (Yellow Poinciana), T1, and *Ficus elastica* (Indian rubber plant), T2, are Asian trees but they are planted successfully in Cairo for their shading and ornamental values. The *F. elastica* also called *Ficus decora* is an evergreen tree with 12–15 m mature height, 6–9 m corresponding height and 4–6 trunk height. The *Yellow Poinciana* is a deciduous tree can reach up to 20 m height with 12–16 m corresponding height and up to 6 m trunk height. T2 is not dominantly used as urban street tree whereas T1 is widely. Fig. 1 demonstrates both trees [47,48].

In C1, trees were arranged in front of F2_B2 in both cases in two positions, so that each has two trees. On the other hand, F1_B1 facades have one tree for each to allow more air access to between buildings and generating shadows for pedestrian at low solar altitudes, refer to Fig. 2. In C2 the non-uniform distribution of trees planted is replaced with a linear distribution that has same trees arrangements as described formerly. It is of importance also to mention that position of trees in relation to buildings is critical as the shadow produced and wind speeds are affected in turn [49], but this is beyond the scope of this study. However, trees in this paper are allocated at 1.5 and 4 m distance away from the building plots in C1 and C2, respectively, Figs. 2 and 3.

Table 1
Abbreviations used in the study.

Symbol	Meaning
C1	Site case no.1; Fifth Community
C2	Site case no.2; Misr Al-Gadida
B1	Northern Building in each case
B2	Southern Building in each case
F1	Northern façade in each building
F2	Southern façade in each building
BC1	Base case one of the 5th community
BC2	Base case two of Misr Al-Gadida.
T0	No trees; the base case situation of site one
T1	*Peltophorum pterocarpum* (Yellow Poinciana).
T2	*Ficus elastica* (Indian rubber plant).
T3	*Ficus nitida*; the base case tree of site two.

Table 2
Meteorology inputs used in simulations for the 7th of June.

No.	Parameter	Value
1	T_a	300.55 °K
2	RH	51%
3	V	3.5 m/s at 10 m height
4	Ground temperature	299.25 °K from 0 to 0.5 m and 297.15 °K from 0.5 to 2 m
5	Ground humidity	20% from 0 to 0.5 m and 30% from 0.5 to 2 m
6	*U* value walls	1.7
7	*U* value roofs	2.2
8	Albedo walls	0.25
9	Albedo roofs	0.15
10	Albedo pavement	0.40
11	Pavement emissivity	0.90
12	Stomata resistance	400
13	Root area density, RAD	0.1
14	Albedo leafs	0.20

2.4. LAD generation

Leaf area density spatial distribution introduced for ENVI-met simulations [43] in two steps. First, the minimum LAD of the tree is calculated using software compiled in Fortran by authors based on the empirical LAD model of Lalic and Mihailovic [41]. This model was solved 10 times to produce LAD values at different heights of the tree using the tree height h, the maximum leaf area density L_m, and the tree canopy corresponding height z_m. In the second step, LAD results were added to ENVI-met plants database to represent the 3-D canopy of these trees. Consequently, these trees were introduced to the model area and simulated, regardless the many ways of field measurements of LAI; it was a research question to investigate modeling of a tree canopy in absence of measured value. The maximum LAD, L_m, needed in the LAD model have been derived by assuming LAI value.

In this respect, the ground level shape of tree shadow that depends on the light transmission profile has been suggested regarding trees plantation objective. Plantation objective mean the purpose or the aim of planting a tree, is it ornamental, functional, etc [29,30]. In this work the objective is to produce maximum ground shadow at peak time of Cairo. Eventually, a specific thermal performance and modifications towards a tree microclimate can give it preferability from another one.

Fig. 1. (a, b) The *Ficus elastica* (Indian Rubber Tree) to the left, the *Peltophorum pterocarpum* (Yellow Poinciana not in mature height) to the right.

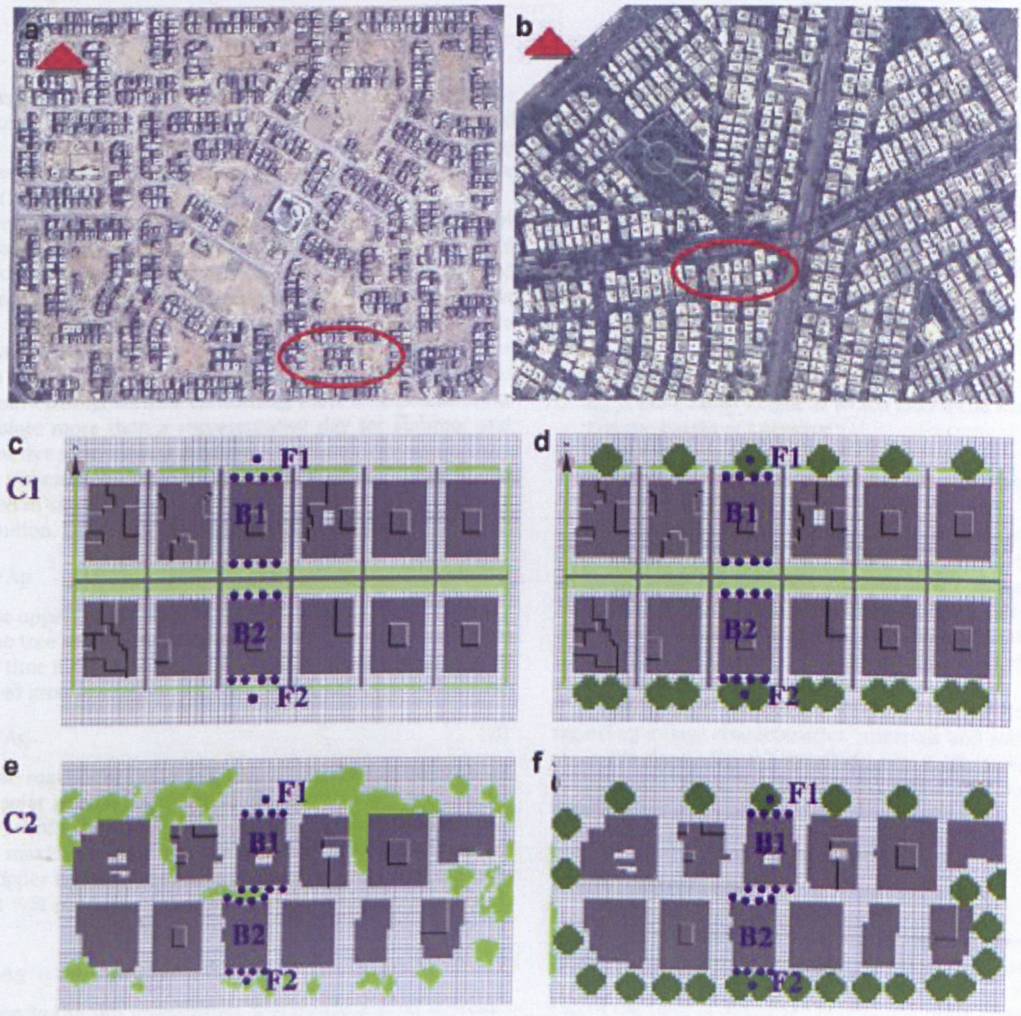

Fig. 2. (a, b) The 0.6 m resolution Quick bird 2008 satellite images indicate location of sites in the study. (c–f) Illustration of sites before and after trees modifications with buildings and facades examined surrounded by snapshot receptor points; C1 is top and C2 is bottom.

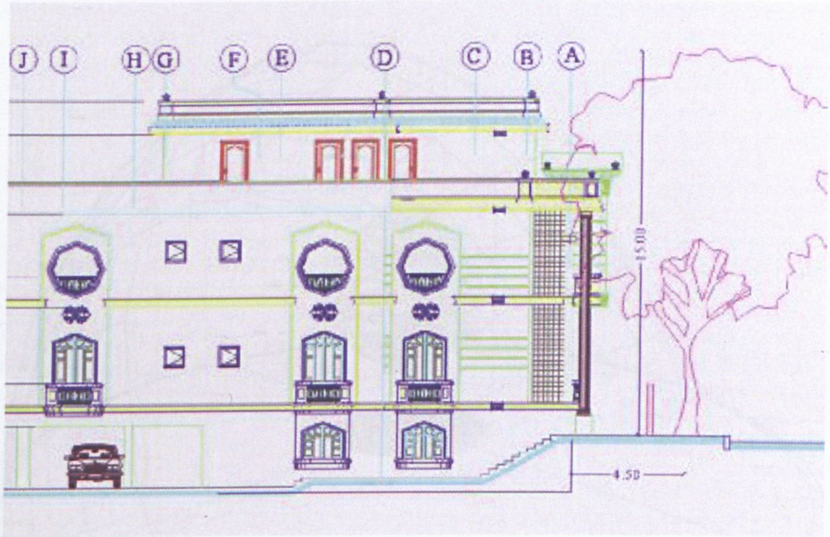

Fig. 3. Side façade CAD illustration for the building-tree relation that could affect walls shadow, example is a design for the first author in C1.

With regard to the solar position, the average peak solar altitude in the typical summer hot week is 82.40° (between 82.80°and 82.10°) at 13.00LST. This was on the 7th of June of the typical summer week, despite that altitude reaches 83.3° in the extreme hot week (26th of June–2nd of July).

However, this day conditions were simulated as a typical hot summer day at the middle of the typical summer hot week (5–11 of June) based on 30 years of WMO Station no.623660 records at Cairo international airport [45]. Simulations were held for the peak solar 6 h from 10.00 to 16.00 LST, attributed to only studying the microclimatic effects, neither to calculate the comfort levels for pedestrian nor to study buildings interior climate. In addition, as ENVI-met simulations are time consuming, there is no possibility at all to simulate more than a representative day for summer and a representative time for day shading.

Table 2 indicates the main meteorological daily average inputs of June used in simulations.

By definition, LAI can be represented as following:

$$LAI = AL/Ap \tag{A}$$

AL is the upper leaves area.

Ap is the tree ground planting area.

At peak time if the shadow is solid, then Ap should almost equal the projected ground shadow, Ag. Thus Eq. (A) can be converted to:

$$LAI = AL/Ag. \tag{B}$$

Ag is the maximum projected ground shadow of the tree at maximum solar altitude, (13.00 LST).

In other words, the least value for LAI to produce a solid ground shadow at maximum solar altitude of nearly 90° (peak time), is when the upper leaves area equal that shadow area, i.e. if the tree modeled, it will produce solid shadow with minimum amount of leaves; or

$$LAI = AL/Ag = AL/Ap = 1 \tag{C}$$

In relation to the site investigated, this means a good approximation of applying this LAI value when the altitude is 82.40° of the simulated day, the 7th of June, Fig. 4.

Hence L_m of the minimum LAI of maximum shading effect can be calculated from the model equation as following;

$$LAI = \int_0^h L_m(h - z_m/h - z)^n \cdot \exp[n(1 - h - z_m/h - z)] \cdot dz \tag{D}$$

Substituting L_m in the following equation, so that LAD can be calculated for any z;

$$LAD = L_m \cdot (h - z_m/h - z)^n \cdot \exp[n(1 - h - z_m/h - z)] \tag{E}$$

h, is the total height of the tree.

z_m, is the canopy height at which LAD is the maximum (L_m).

z, is the height of LAD slice.

$n = 6$ if $0 \geq z \geq z_m$, and 0.5 if $z_m \geq z \geq h$.

The compiled software solved Eqs. (D) and (E) to automatically record LAD values needed for ENVI-met database.

Moreover, for any tree, if h, L_m, and z_m do not ensure that LAI = 1, this means that the ground shading will be filtered rather than dense or solid, the tree will transmit larger amount of radiation. Thus, LAI = 1 can be used as a benchmarking reference value for urban trees of semi-arid Mid Latitude region in which Egypt lies, where solar height angle is close to 90° and the shadow area will be almost equal to the planting area.

Other foliage parameters in the original database, inputs regarding foliage characteristics, materials and soil types for both cases are fixed, Table 2 to allow only a comparison of thermal performance based on the differentiated LAD values and sites details.

2.5. *Parameterization*

In order to study LAI of 1 trees base performance on the selected fabric as an example of urban developments, snapshots were placed in three groups around. Each of them has eight snapshots except the third is composed of only one point under trees outside the plot limit, Fig. 2 (c–f). First and second groups consist of four points for best interpreting each parameter average from the four

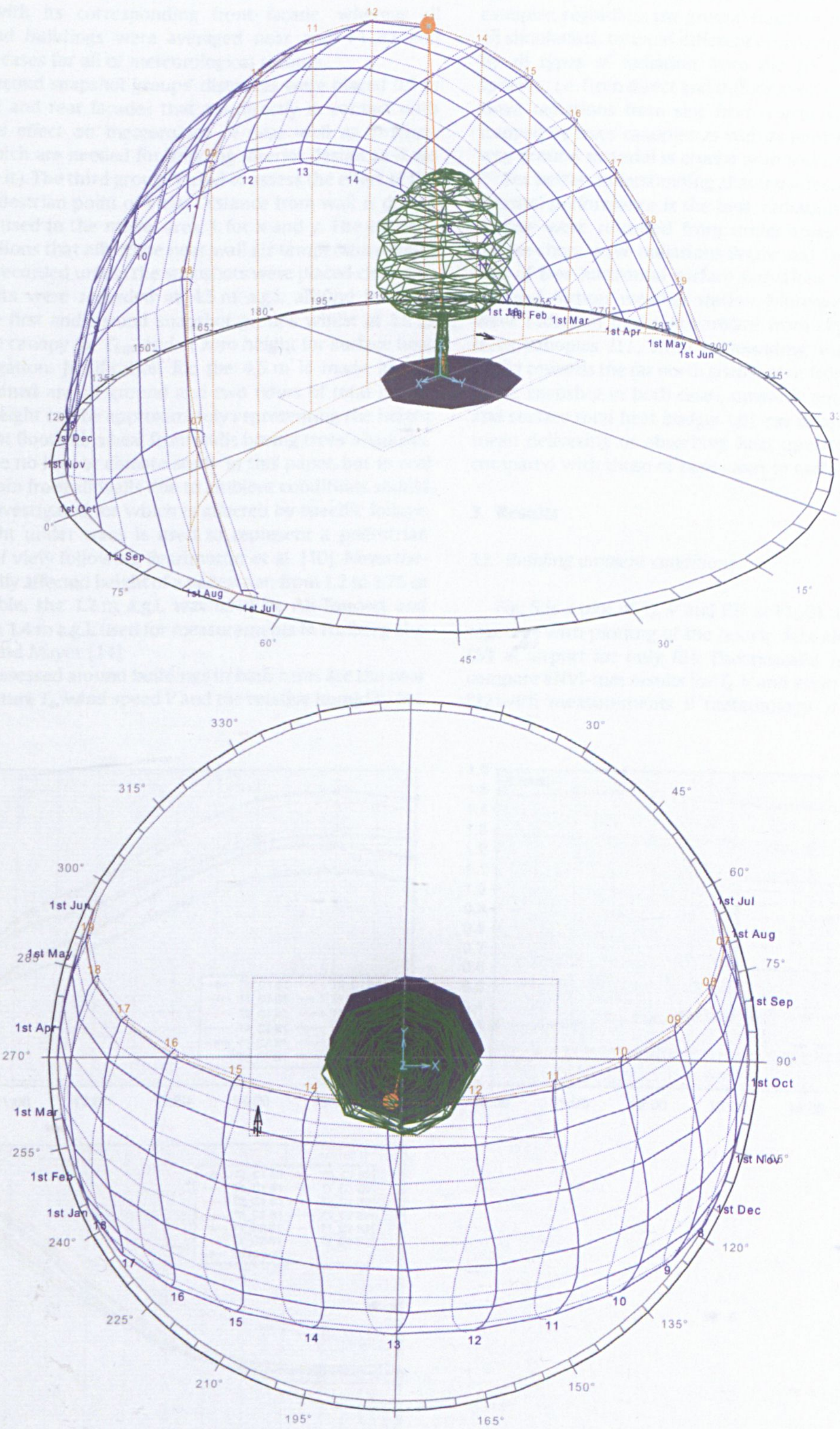

Fig. 4. Schematic model by ECOTECT 5.6 for the Yellow Poinciana (following Shahidan et al., [36]) to indicate shadow of solar altitude of 82.40° on the simulated day, the 7th of June at peak time of 13.00 LST, which is almost equal plantation ground area; i.e. the least LAI should be 1.

records. Rear façades' snapshots were only used for wind speed comparison with its corresponding front façade, whereas all outputs around buildings were averaged near only F1_B1 and F2_B2 in both cases for all of meteorological records.

First and second snapshot groups' distances were placed 0.5 m from the front and rear facades that are directly in contact with trees to assess effect on meteorology of near wall as ambient conditions (which are needed for building interior design as if we are going to do it). The third group is used to assess the effect of the tree from a pedestrian point of view. Distance from wall is due to the resolution used in the model area, 1 for x and y. The efficient radiant interactions that affect the near wall air temperature could not have been recorded unless the snapshots were placed closest to facades. Outputs were recorded at 4.5 m a.g.l. around building facades for the first and second snapshot groups whilst at 1.5 m a.g.l. under tree canopy for T_{mrt} and at zero height for surface heat budget investigation. Justification for the 4.5 m is made as the buildings examined are all ground and two floors of total height 9 m, so 4.5 m height can be approximately representing the height at which the first floor gains heat from walls having trees' shadows. Yet there will be no indoor climate study in this paper, but in real practice, heat gain from all walls due to ambient conditions should be accurately investigated for which is affected by specific foliage. The 1.5 m height under trees is used to represent a pedestrian comfort point of view following Pearlmutter et al. [10]. Nevertheless, the thermally affected height of a pedestrian from 1.2 to 1.75 m a.g.l. is acceptable, the 1.2 m a.g.l. was used by Ali-Toudert and Mayer [6] and at 1.4 m a.g.l. used for measurements in Freiberg also by Ali-Toudert and Mayer [14].

Parameters assessed around buildings in both cases are the near wall air temperature T_a, wind speed V and the relative humidity RH.

T_{mrt} as a pedestrian comfort indication is recorded under trees' canopies, regardless the ground finishing material which is fixed in all simulations to avoid different emissivity, Table 2. T_{mrt} is affected by all types of radiation from the six directions of both hemi spheres; i.e. from direct and diffuse short-wave radiations, all long-wave radiations from sky, from surrounding built environment, trapped by trees canopies as well as emitted from ground that are why ground material is crucial with soil underneath.

For better understanding shadow effects and in turn which tree thermal performance is the best, radiation components at ground surface were recorded from under trees' snapshots. Direct and diffuse short-wave radiations Sw.dir and Sw.dif are compared with that of free horizontal surface radiations recorded at Cairo International Airport weather station. Moreover, the air-surface long-wave radiation fluxes downward from sky $Ls\downarrow$, downward from trees canopies $Lt\downarrow$, from surrounding walls $Lw\leftrightarrow$ (either from F1_B1 towards the far north snapshot or from F2_B2 towards the far south snapshot in both case), upwards emitted from ground $Lg\uparrow$, and surface total heat budget $Lp\updownarrow$ (as total budget at a time could mean delivering or absorbing heat upwards or downwards), are compared with those of base cases in each site.

3. Results

3.1. Building ambient conditions

Fig. 5 is a plot of T_a, V and RH at F1_B1 and F2_B2 in both sites together with plotting of the hourly data also from 10.00 to 16.00 LST at airport for only RH. Theoretically, it could be possible to compare ENVI-met results for T_a, V and RH in a mid latitude location [22] with measurements if meteorology at boundary conditions

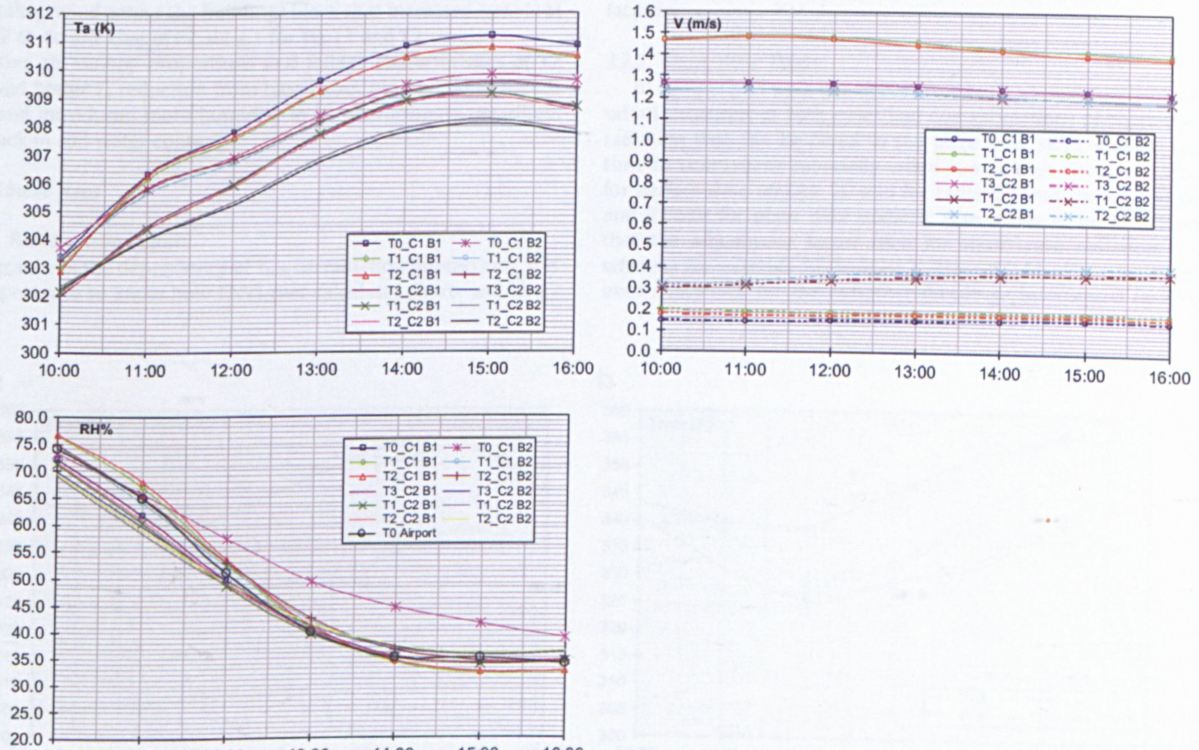

Fig. 5. Comparison of T_a, V, and RH at F1_B1 and F2_B2 in both sites, respectively.

were adjustable, height of simulated records within urban canopy layer equals its corresponding measured and if these heights assure blending between the roughness sub-layer and the urban canopy layer in both sites [50]. ENVI-met calculates T_a, V and RH from the initial inputs which are kept constant. Future development of the software could consider forced daily measurements, but limitations still exist. It was worth plotting results of RH from simulations with that of airport station as they were found to have nearly the same profile and ranges as if the trees were not exist in the model at all. It has been recognized that evapotranspiration did not take place effectively because there was not enough water content in soil under trees. The water content after all simulations for all receptors ranges only from 0.08 to 0.14 m^3/m^3 at different depths due to the soil reduced humidity input, i.e. almost no water has been applied for trees and hence the fixation of water content at 1.75 m depth by ENVI-met did not affect. This clarifies why humidity environment of trees was close to the measured at airport although it has increased by usage of T2 compared with T1 with minor difference of 1–3% between them. This lack prevented increase of latent heat and allowed increase of sensible to balance the foliage irradiative budget concluding with no valuable difference in T_a. Despite values differences did not exceed a negligible value of 0.1–0.3 K, the 0.3K was assigned to using T2 which has the denser canopy than T1 due to higher LAD values. Wind speeds also did not help reducing T_a. It is generally in both sites about 1.1–1.5 m/s at F1_B1 that face prevailing wind from north and reduce to about 0.1 m/s at F2_B2. Wind records ranged from 0.1 to 0.3 m/s in between rear facades. Overall wind speeds recorded were reduced about 60–95% from the initial simulation input of 3.5 m/s due to trees and the urban form wind blocking even in cases without trees. The usage of T1, which has the smaller LAD values, reduced wind speeds in both sites rather than the usage of T2 because of its height. In C2 the slight rotation from E–W helped increased speeds due to the angel of attack from prevailing wind across the buildings block that increased speeds at F2_B2 to double that of F2_B2_C1 for T0, T1 and T2.

After all, canopy proportions and foliage characteristics of T2 showed better T_a reduction from base cases, blocked wind speeds less and introduced more humidity to its microclimate regardless the lack in soil water content.

3.2. Under trees

3.2.1. Radiant temperature

Because of the dependency of T_{mrt} on radiation interactions, it is of importance to know how ENVI-met calculates short- and long-wave radiation as they conclude the T_{mrt} value. The heat budget at any point on the ground surface or in the model atmosphere is generally calculated by modifications to the radiation sources due to buildings and plants using SVF and the vegetation foliage transmission factor [43]. It is a place to mention that work held in this paper revealed issuing new BETA version of ENVI-met because of the trees transmission factor [51], that has not operate effectively as if the trees does not exist in the model and simulations had to be repeated twice.

However, as described formerly there is no influence from the model boundary conditions. Hence, unlike comparing T_a, V and RH of simulations with airport measurements, radiation can be compared in order to address the different masking effect of different trees' foliage at specific height a.g.l., regardless some gases' effects (carbon dioxide, etc) are not included.

Fig. 6(a, b) represents T_{mrt} of both sites. T_{mrt} as a biometeorological representation of all wave radiations influencing pedestrian comfort under trees canopies is attributed to solar movement. The southern snapshots recorded lower values at early and late simulated time rather than the northern one in comparison to base case of each site. For example, in C1 at 10–11.00 LST values for F2_B2 were 346.4°/T0, 329.6°/T1 and 324.0°/T2K, C2 values were 345.3°/T3, 331.5°/T1and 328.5°/T2.

At early simulated time, higher values of Sw.dir were recorded rather than at peak hours of 12.00–14.00 LST because of the combined effect of trees and buildings. But at peak time, T2 performed better in both sites with about 3K difference in C1 and 7K in C2. At early evening $Lg\uparrow$ start to be emitted and increase T_{mrt} which recorded about 6K less by using T2 than T1 at C1 and 11K less by using T2 than T1 at C2. Further T_{mrt} drop at 14.00–16.00 LST in both cases is attributed to site orientation where direct radiation is blocked by buildings and with tremendous drop in C2 because of the more deviation from N–S orientation of facades.

3.2.2. Short-wave fluxes

In comparison with the airport free horizon measurements, all urban situations of both cases had overestimations of short-wave radiation that can be owed to the large time steps used to save time in simulations especially when sun at high altitude (15 min for surface data update, 20 min for radiation and shadow update and 25 min for plant data update). Also it has to be mentioned that the adjustment factor used for short-wave radiation is 1, whereas for example Ali-Toudert [22] used 0.84 which mean that overestimations for the radiation should be intercepted by trees

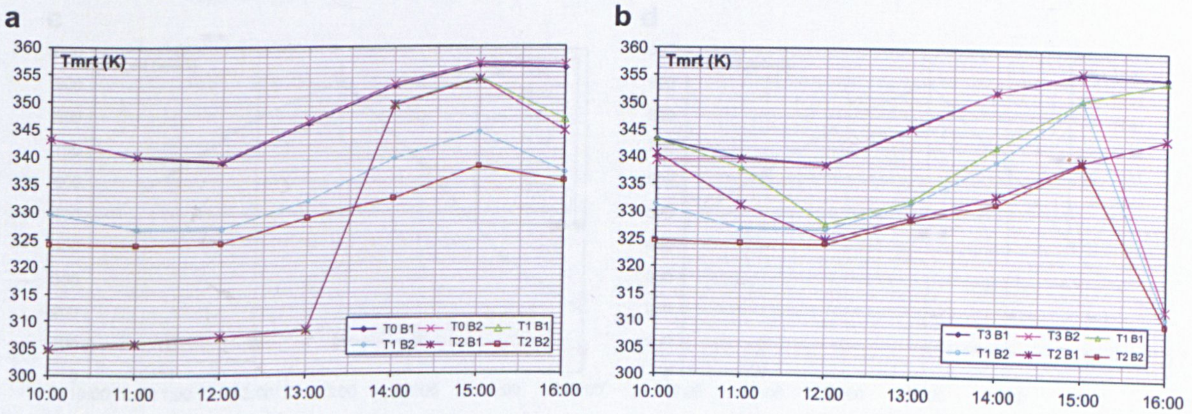

Fig. 6. T_{mrt} at F1_B1 and F2_B2; left is C1 and right is C2.

are included. The much difference came when sun at low altitude due to obstacles from environment. This later reason particularly made the diffuse (include diffusely reflected) radiation output from ENVI-met for BC1 and BC2 much less than measured in Airport. Fig. 7 (a–d) illustrates *Sw*.dir and *Sw*.dif for both sites.

In C1, at peak time *Sw*.dir values for T0 in front of both facades were equal and almost as the free horizon. By usage of T1 records were 768/F1_B1 and 597/F2_B2 w/m^2(about 40% of direct radiation incident on the tree) and for T2 recording 547/F1_B1 and 522/F2_B2 w/m^2 (about 50%). About 100 w/m^2 of intercepted direct radiation were recorded by the foliage of *F. elastica* rather than the *Yellow Poinciana* in both sites.

In C2 almost same discipline has been noticed for *Sw*.dir, although orientation and the base case details made more discrepancies from the free horizon measurements. Values at peak time were 600 w/m^2 for both under trees' snapshots of T1 and 525 w/m^2 for both under trees' snapshots of T2 respectively whilst snapshots of T3_BC2 generated almost same as Airport. This was due to position of snapshot that was not exactly under trees, besides the buildings examined in C2 almost was not having trees near facades, which approved the need for additional simulations. Nevertheless, records give an initial indication that T2 in both cases made environment perform better than T1 subject to more investigation for all T1, T2 and T3. The reduced records of *Sw*.dif in both sites are attributed to built environment and trees that blocked much of airport measurements values 900 w/m^2 to reach not more than about 90 w/m^2 in situ.

3.2.3. Long-wave fluxes

Understanding results of all long-wave radiation components under trees is better to be related at first to the LAD values of both T1 and T2 canopies foliage characteristics. The integration of LAI of 1 actually has distributed same amount of leaves over the different canopy heights of both T1 and T2. Consequently, the one of them that has more canopy height will be less foliage density and more transmitting for *Sw*.dir and *Ls*↓ which mean initial preference of T2 than T1.

Fig. 8 illustrates long-wave radiations from sky, from environment, from trees, emitted from ground and the total budget of pavement surface in both sites.

Amounts of heat trapped by canopies are attributed to *Lt*↓ (either due to *Ls*↓ or due to *Sw*.dir) or as part of the emitted *Lg*↑. These amounts heat microclimate environments, and have to be considered in assessing effects of specific canopy profile.

Basically, by means of *Sw*.dir, *Lw*↔ and *Ls*↓, the ground initially receives radiation then heat stored in pavement tiles under trees. Pavement has an Albedo of 0.4 and an emissivity factor of 0.9 and the deep soil contained not more than 30% of RH which mean high rate of sensible heat will take place. The pavement material can play a role to giving chance for more dense trees. As emissivity increases more trapped heat by dense canopies will increase and vice versa.

The most effect of trees was on the radiation from sky, trees intercepted about 120–150 w/m^2 by T1 and T2 more than T0 or T3 respectively. In both cases usage of T2 reduced *Ls*↓ by about 20–30 w/m^2 at F1_B1 and F2_B2 more than usage of T1 due to T2 LAD. The orientation of buildings also in both sites affected all amounts

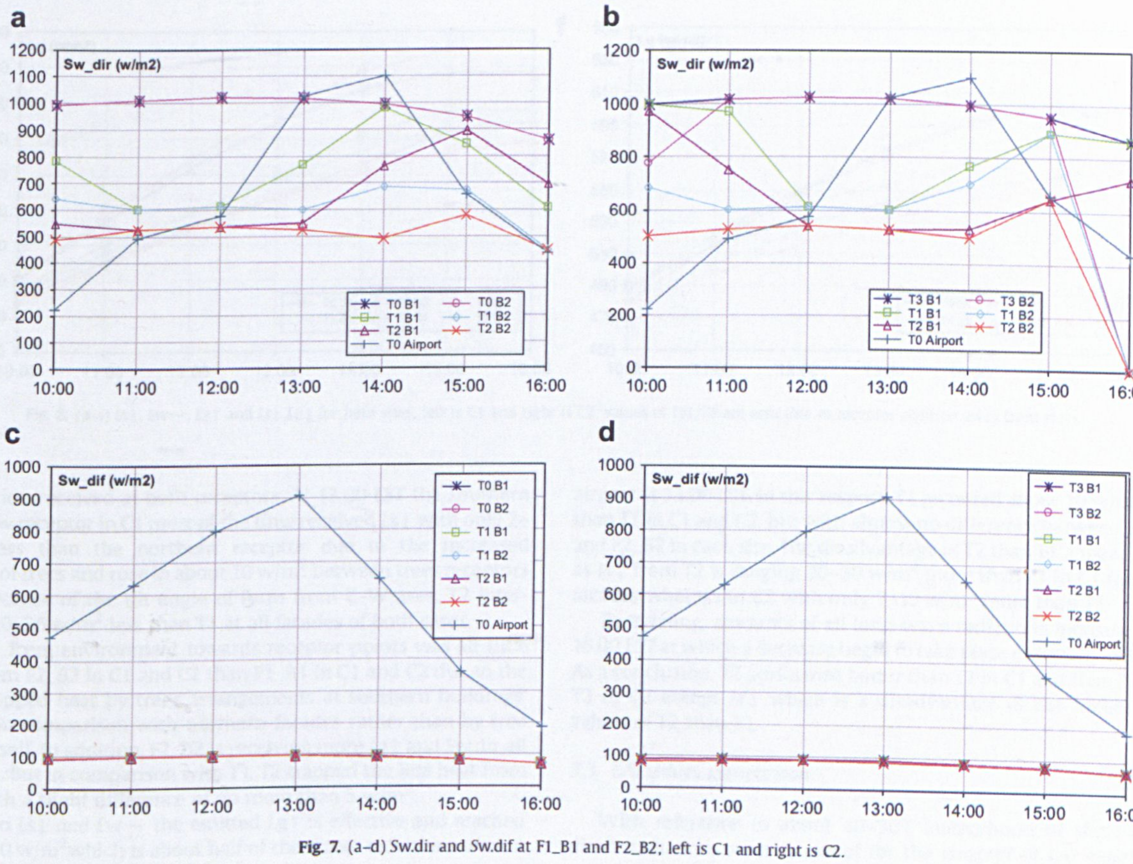

Fig. 7. (a–d) *Sw*.dir and *Sw*.dif at F1_B1 and F2_B2; left is C1 and right is C2.

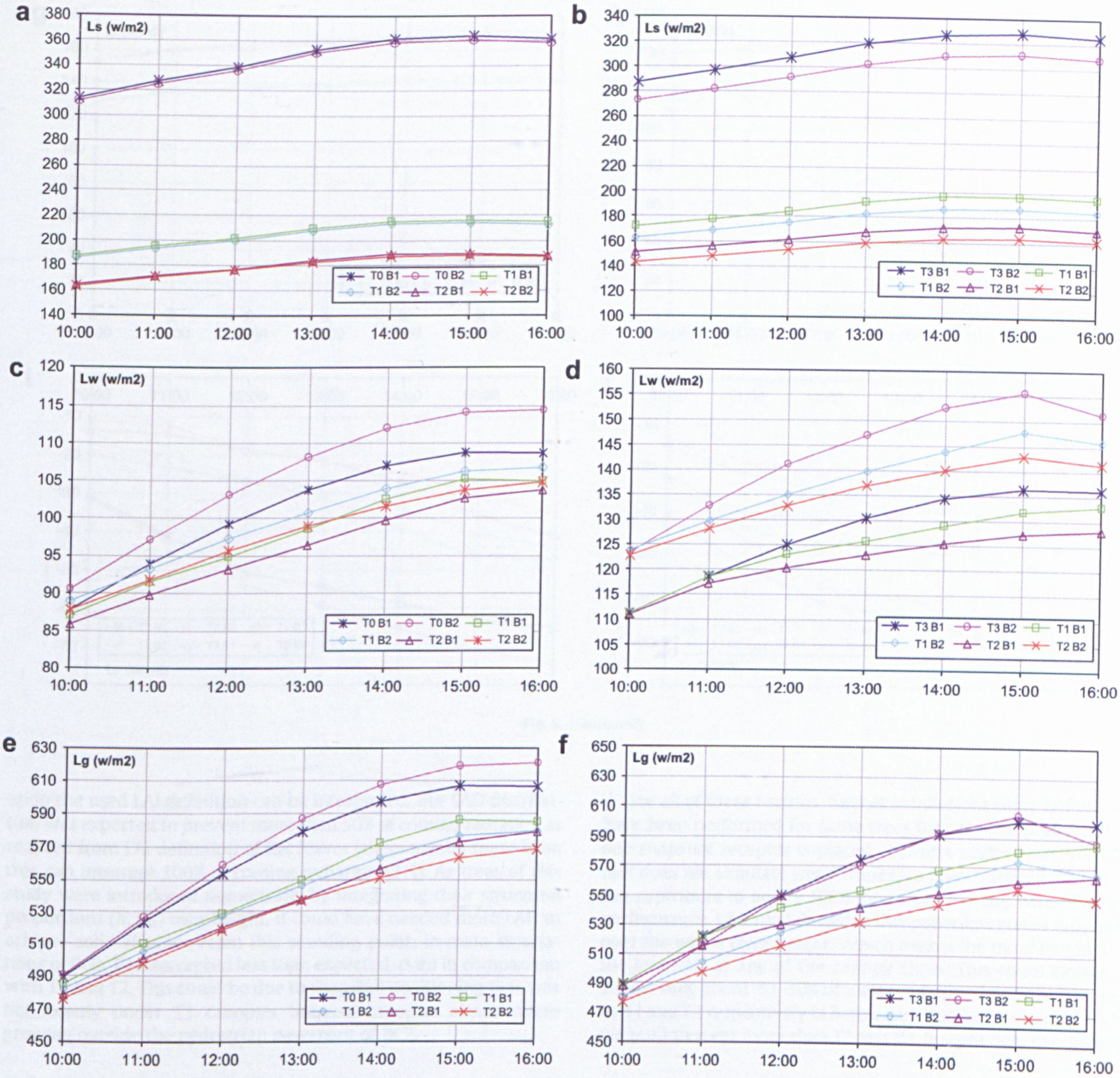

Fig. 8. (a–j) $Ls\downarrow$, $Lw\leftrightarrow$, $Lg\uparrow$ and $Lt\downarrow$ $Lp\updownarrow$ for both sites; left is C1 and right is C2, values of $Lt\downarrow$/T3 are zero due to receptor position away from trees.

of radiation received at both receptors. At 13.00 LST the southern trees' row receptor in C1 most of the time received $Ls\downarrow$ with only 2–4 w/m^{2}less than the northern receptor due to the increased number of trees and rose to about 10 w/m^2 between trees receptors of C2 because of the tilt angle of form from E–W axes. T2 intercepted 20–25 w/m^2 less than T1 at all facades of both cases.

$Lw\leftrightarrow$ from environment towards receptor points was all time more from F2_B2 in C1 and C2 than F1_B1 in C1 and C2 due to the more trapped heat by trees arrangements at southern buildings' facades in comparison with northern facades rather than by tree foliage itself. In addition, F2_B2 is receiving more $Ls\downarrow$ and *Sw*.dir all day time. But in comparison with T1, T2 trapped the less heat from walls with a slight difference of no more than 5 w/m^2.

Due to $Ls\downarrow$ *and* $Lw\leftrightarrow$ the emitted $Lg\uparrow$ is effective and reached about 540 w/m^{2}which is about half of the direct radiation value at airport at 13.00 LST. In this respect, T2 recorded about 10 w/m^2 less than T1 in C1 and C2, but with almost no difference between F1_B1 and F2_B2 in each site. The disadvantage of T2 than T1 appears here as $Lt\downarrow$ from T2 is ranging 20–30 w/m^2 more than T1 in C1 for both facades whereas in C2 with only 7–10 w/m^2 more than T1.

By evening, amounts of all long-wave radiations increase until 16.00 LST at which a decrease begin to take place especially with T2. As a conclusion, T2 performed better than T1 in C1 and than T1 and T3 in C2 except $Lt\downarrow$ which is a disadvantage of the higher LAD values of T2 than T1.

3.3. LAI values comparison

With reference to about 40–50% interception of short-wave direct radiation, a partial proof for the concept of LAI equal one

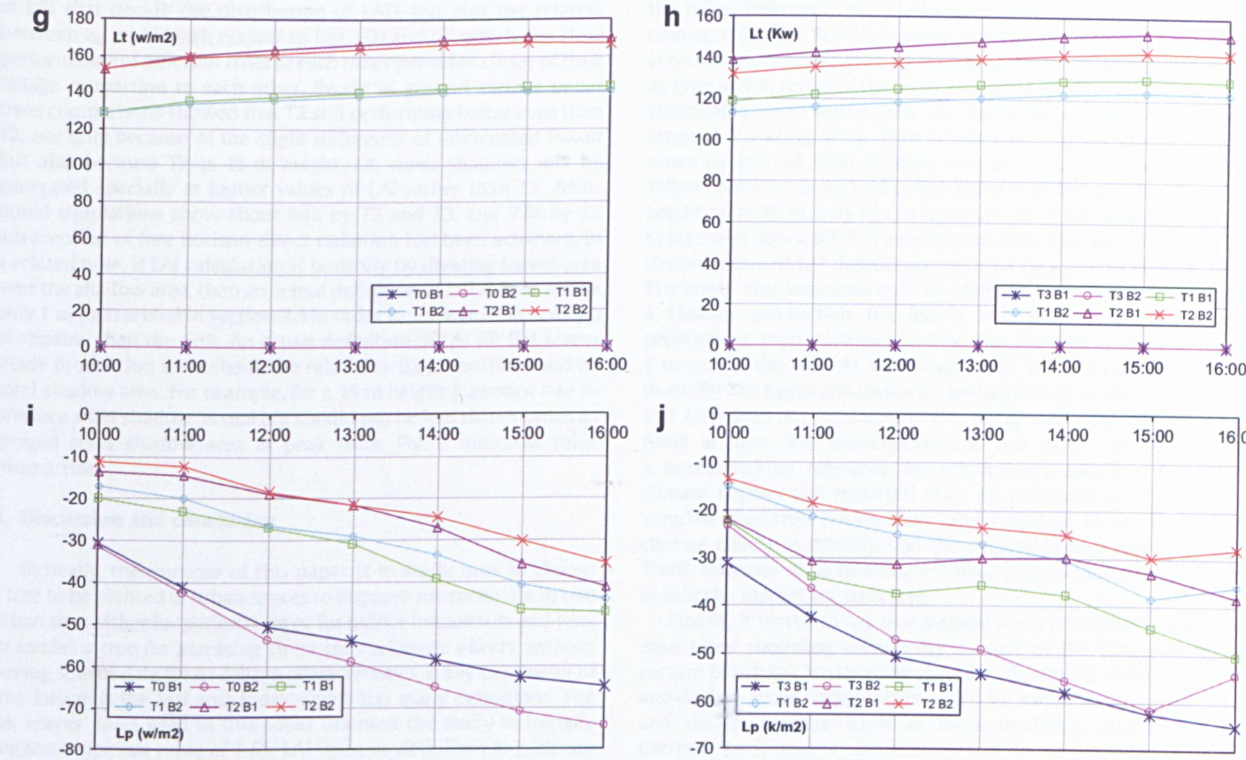

Fig. 8. (*continued*).

upon the used LAI definition can be interpreted. But LAD distribution was expected to prevent more than 50% of coming radiation as realized from LAI definition of flat leaves (theoretically there is no tree can intercept 100% of coming radiation [21]). As trees of this study were introduced numerically by integrating their structural proportions (h, z_m) over height, it could have needed more LAD to achieve solid shadow. From this standing point, in main simulations of BC2, T3 intercepted less than expected, even in comparison with T1 and T2. This could be due to snapshot positioning that was not exactly under T3 canopies because canopies almost were growing outside the pedestrian pavement of BC2.

For all of these reasons, further simulations using LAI of 2 and 3 have been performed for same trees for only the peak hour. Only one snapshot receptor is placed at centre under each tree (ENVI-met does not simulate trees' trunks) to investigate which LAI value can contribute to nearly 100% interception along with assuring T3 performance. LAD model used in this paper integrated only LAI of 1 over the whole trees height. Which means the more height of tree, the less LAD at any of the canopy slices. This could explain why almost only about 40–50% of direct radiation has been intercepted by T1 and T2 respectively in both cases. But does not explain why T3 did not intercept more than T1 and T2. It is not only the integration

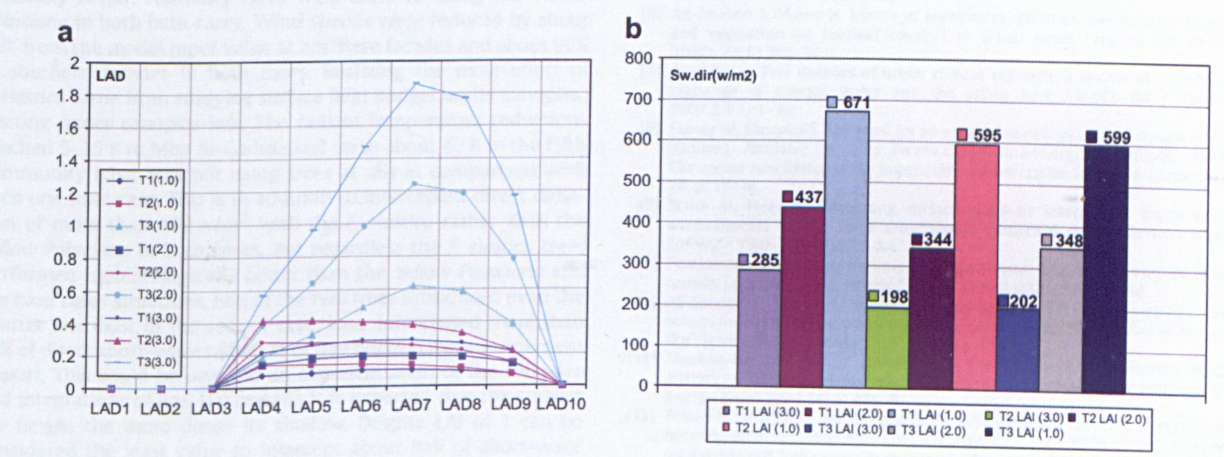

Fig. 9. (a) LAD values of T1, T2 and T3 upon 1, 2 and 3 LAI. (b). Short- and long-wave radiations recorded under trees upon different LAI values at 13.00 LST.

of LAI that decide the distribution of LAD, but also the relation between z_m and h with respect to Eqs. (D) and (E) which can close performance of different trees to each other provided closer of their foliage proportion to each other. Sw.dir at ground surface under trees comparisons showed that T2 still performing better even than T3, not only because of the slight difference of intercepted Sw.dir but also because T2 is 15 m height, i.e. more shadows will be generated specially at higher values of LAI rather than T3. Additional simulations show about 84% by T2 and T3, and 73% by T1 interception of free horizon direct radiation has been achieved. In a related note, if LAI calculation is basically by dividing leaves area over the shadow area, then an actual definition of LAI should not be only 1 as interpreted in Section 2.4 in order to achieve more solidity of shadow than the 50%. An actual definition of LAI for flat leaves shade production trees should be related to its proportions and its solid shadow area. For example, for a 15 m height *F. elastica* tree to produce solid shadow, actual LAI should not be less than 3 times its ground solid shadow area at peak time. Fig. 9 indicates value comparison.

4. Discussion and conclusion

Basically, the purpose of this paper is to study how to choose a tree to be planted in urban spaces to improve microclimate in two urban sites either for pedestrians or for indoor inhabitants and how to model a tree for assessing these microclimatic effects without having source data for its foliage characteristics. A key parameter of tree foliage is the leaf area index which has many definitions. The flat leaves' trees used in this paper oriented the study to initially suggest empirical value of 1 for LAI upon its definition to generate solid shadow. In order to check such LAI based trees' performances, numerical simulations using ENVI-met took place for the cases' environments with these trees. The canopies' LAD profiles have been generated to be used within ENVI-met plants database. Main simulations in completion with additional ones indicated that, when selecting a tree, the more height the more need to increase leafs to conclude more density for more interception but with caution to long-wave radiation trapped by canopies. Optimization between ground surface physical properties and the amount of heat trapped by a tree could help increasing LAI value of a specific tree so that more direct and sky radiations can be intercepted. In this study, the *F. elastica* performed better than the *Yellow Poinciana*. Although air temperature records showed about 0.1–0.3 K reductions from both base cases due to the reduced wind speeds and lack in soil water that prevented evapotranspiration effects, it performed generally better. Humidity rates were close to using the *Yellow Poinciana* in both base cases. Wind speeds were reduced by about 60% from the model input value at northern facades and about 95% at southern facades in both cases. Realizing the most effect of *F. elastica* came from studying surface heat budget under canopies; heating under canopies less. The radiant temperature reductions reached 5–15 K in Misr Al-Gadida and up to about 40 K in the Fifth community (that was not using trees at all) in comparison with each one base case. This is in addition to intercepted direct radiation of more than 100 w/m^2 with the *F. elastica* rather than the *Yellow Poinciana* in both cases. But regardless the *F. elastica* trees performed meteorologically better than the *Yellow Poinciana* and the base cases situations, non of the two trees introduced even the shorter one exist in the second case, have intercepted more than 50% of direct short-wave radiation of free horizon measurements at airport. This could be owed to an overestimation of the software and integrations of Eqs. (D) and (E), it is expected that the smaller the height the more dense its shadow. Despite LAI of 1 can be considered the least value to intercept about half of short-wave direct radiation by using up to a 20 m height flat leaves tree (such as the *Yellow Poinciana*), more LAI values could have intercepted more coming radiation. Results suggest an actual definition of LAI for flat leaves shadow production trees to be in terms of height regardless its type and in terms of the peak time solid shadow rather than the changeable upper leaves area, i.e. specific definition for each trees range of h and z_m. For a 15 m height tree for example; it is three times its ground solid shadow area at peak time. Hence, if the *Yellow Poinciana* examined in this paper is to be used for a housing height up to 20 m, may be not less than LAI of 4 should be this tree to intercept about 100% of coming radiation. This way can solve the discrepancies of LAI definitions reported by Jonckheere et al. [34]. The study also indicated that, to interpret an actual LAI value for a shadow production flat leaves tree with a specific foliage proportions, methodologically, first; test the empirical value LAI of 1 to model the tree. At a semi-arid mid latitude regions starting from 30° like Egypt and towards low-latitude sites, any tree of h, L_m, and z_m if does not validate LAI of 1, the ground shading would not fulfill at least 50% interception and this value can be used as a benchmarking reference for urban trees selection. For other climate regions the empirical start for LAI could be 0.5. Second, simulate this tree environment and calculate its corresponding climate effects to initially find the preferable tree among others. Third, estimate its approximate 100% interception LAI value then search the market for such tree.

Finally, it worth to say that despite work presented is a trial to ease trees' modeling complexity as part of the bigger complex picture of urban climate to be linked with applied urban planning and design, more complication might be added to urban planning and design practice itself as trees modeling and LAI based thermal performance assessment has to be included in such practice.

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Urban form adaptation towards minimizing climate change effects in Cairo, Egypt

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ABSTRACT

This paper examines the role of urban form adaptation in reducing CO_2 production in a hot semi-arid neighborhood in Cairo, Egypt. Adaptation is represented by mean outdoor comfort responding to urban form modifications. Form emissions has been considered mainly from mechanical cooling' equipments and appliances whilst plants photosynthesis and anthropogenic sources were fixed. Three suggested master plans passively designed were numerically simulated. Eventually, CO_2 emission of a selected building was investigated in terms of the different master plans effects. At solar peak, coupled outdoor-indoor comfort as well as CO_2 production showed reductions with same trend in comparison with the base case by the first suggested urban form design. Second and third designs timely shifted all parameters representing form heat gain and release which is defined as the urban thermal mass effect. CO_2 production was reduced by about 1.7 and 2.8% for second and third suggestions whilst the first increased it by 0.6%.

Key words: Urban thermal mass, Coupled Comfort, EPW, CO_2.

1. INTRODUCTION

It is believed that climate change is owed to urban population increases, human welfare and the worldwide industrial growth. The direct impact was and still the increasing green house gases, GHG, emissions, of which carbon dioxide is playing a big role. Just to mention not to cumulate, impacts broadened from higher temperature and health issues up to floods and energy consumption increases ending with completely different master plans for urban developments to adapt cities in the next few decades [1-8]. Eventually, reducing GHG specifically in the residential and industrial sectors throughout an efficient adaptation methodology, [9, 10], took place in many governmental polices for industrial sectors but didn't take place residentially away from controlling CO_2 emissions on the building scale or cooling surfaces by increase of urban vegetation and reduce materials' heat capacities on bigger scales [4, 11]. Residential sector adaptation for reducing carbon emissions could be more effective by urban form local scale adaptation in completion with single building scale policies. Urban form adaptation is a higher scale of climate based responsive urban planning through adjusting the geometry of the fabric, structuring vegetation along with cooling surfaces; i.e. usage of urban passive cooling techniques [2, 11-15]. Fahmy et al. [13], argued for specific dimensions between green cool islands using human being walking speed and his maximum walkable distance. As the neighborhood is considered the traditional planning unit of a city, [16-20], it should be the climate based adaptive planning of the city. Oke [21] classified the city from urban climate perspective into 5 zones from UTZ1-UTZ7 but did not specify how urban spatial form can benefit in urban planning and communities development. In addition, Duany [20] classified the city from a Transect perspective into 5 zones from T1-T5 but did not demonstrate how traditional neighborhood developments can address different climates. Fahmy and Sharples [14], introduced an intermediate parameter for climate based urban planning that give classification of a city from, the degree of compactness, *Dc*. It represents three parameters; first, the population that decide the built up area as well as second, its height in terms of number of floors to accommodate certain population along with third, the climate response within local canopy height of a specific climate region to close to certain comfort level. By this way, different city zones can be classified into 5 circles (city centre = very compact, central urban = compact, general urban = medium, suburban = open, and rural urban = very open). Consequently, each climate region local scale form and in turn city landscape can have different urban form despite having the same compactness classification. From this standing point, few numerical models were capable of simulating and assessing thermal performance of urban forms due to complexities of its transient environments [22-24]. Moreover, the relation between outdoor climate conditions and indoor climate studies depends on several types of compiled weather data files over periods of time. These files data cannot represent actual climate conditions of a detailed form designed for adaptation. Few studies discussed coupling outdoor-indoor climate conditions to investigate urban comfort based design effect on indoor comfort levels, [25-27], which in turn can imply less energy consumption and CO_2 emissions. in this paper, coupling outdoor-indoor weather data outputs and following and following [27], and urban form design will be presented following [14, 28]. Along with the sequential application of numerical simulations for urban forms to generate ambient meteorology and to study the corresponding indoor thermal comfort levels and CO_2 emissions.

2. METHODOLOGY

2.1 Base case site planning and design suggestions

In order to study local scale urban passive performance, a case located in Cairo (latitude 30° 38' N, longitude 31° 11' E) of hot semi-arid neighborhood area was numerically simulated. Simulations held for the Fifth community which is built in late 20th century, as one of New Cairo communities. It lies to the east of the 1st Greater Cairo's ring road. The base case, BC, master plan can be described as a dot pattern single family villa housing; which is the common feature of New Cairo, the extension of Cairo to the east due to urban development plan of 1982 and its modifications in 1992 [29, 30], Fig.1. It has been converted into urban sprawls accommodation for the rapid growth which increased the problem of Greater Cairo in addition to environmental sustainability problems due its complete dependency on mechanical cooling [14]. Following Fahmy and Sharples [14], and to limit the variation of urban form *Dc* to only the population, the number of floors has been kept same as BC in all design suggestions, in turn the variation in *Dc* appeared in terms of the built up area. DS1 is a clustered urban form planned over BC zoning in order to study the effect of only the clusters regardless orientation or the cluster closure ratio in a mid-latitude site. With ground and 3 typical floors, (G+3), all housing unit either single flat of 150sqm or duplex of 300sqm. DS1, design suggestion no.1, civic services area is same places and land use percentages like BC whereas DS2 of the completely new zoning is having same land uses

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percentage of services but allocated in different zones relevant to the whole quarters of DS2, fig.2. DS2 clusters is designed after [31] who argued for 1:3:1.3 cluster aspect ratio for W/L/H. DS3 is the same like DS2 master plan but with different Albedo for walls and roofs to reduced short-wave direct gain. The clustered fabric form in completion with urban trees' arrangements and the green structure in addition to psychological adaptation aspects reported as passive thermal comfort system by [14] concluded the hybrid form of DS2 and DS3 presented in fig.2. This is following Fahmy and Sharples [28] who investigated how urban form can allow wind access for cooling and health purposes whilst providing shelter from excessive heat gain.

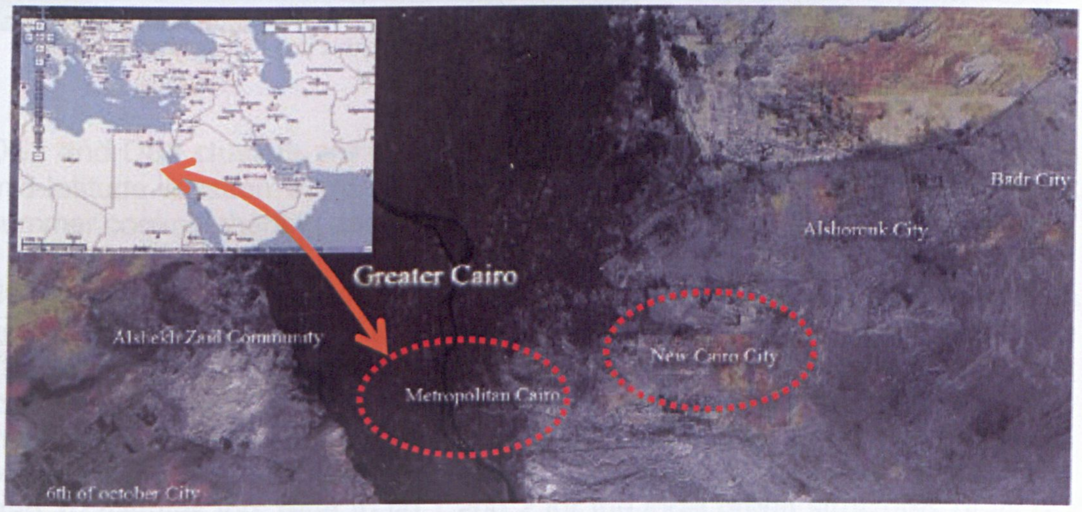

Fig.1a. The Fifth Community in relation to Metropolitan Cairo, Googlemaps.com.

Fig.1b. GIS 3-D modelling built over a Quick Bird 2008 satellite image for the existing case (neighbourhood in scale of about 1 km2 area).

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Fig.2: a, to left is DS1 and b, to the right DS2 and 3 on the modelling tool interface of ENVI-met.

DS2 and DS3 clusters are oriented 15˚ from E-W axis which is optimum for a mid-latitude location same time that the cluster aspect ratio is optimum for summer cooling/shading and winter warming.

BC doesn't almost have any trees planted; all DS1, DS2 and DS3 have 8cm height grass and 15m Ficus Elastica tree that numerically modeled in arrangements using leaf area index, LAI, of 3 after [32]. The green structure is formed so that from each clusters' group in each quarter of the neighborhood; the pedestrian can reach his private or public green area within the 10 minutes walk. Furthermore, to reach the central neighborhood park it won't talk more than 10 minutes too; refer to fig.1 and 2 for the local green structures of all BC and DS master plans. Table.1 show land use percentages and urban planning parameters of all cases.

Table.1: Land use percentages and urban planning parameters.

	Name	Urban area in feddans	Green coverage %, A_g	Urban fabric %, A_c	Average no. of n_f site floors,	Degree of compactness, D_c	Total population in persons
1	BC1	380.15	0.368	0.252	3.171	0.799	14950
2	DS1		0.291	0.299	3.911	1.169	46662
5	DS2		0.476	0.310	4.077	1.264	50448

2.2 Numerical simulations

ENVI-met has proven many advantages towards built environment modeling, simulations and assessment but still having some limitations, [14, 24, 28, 32-36]. Of which the most effective one is the fixation of meteorology inputs at the boundary condition. ENVI-met is a 3-D CFD numerical model that is capable of simulating the built environment surface-air-plant thermal interactions based on the fluid dynamics and heat transfer fundamentals, solar movement and vegetation databases. Simulations using ENVI-met, [33], held for 12h from 06.00 -18.00 LST (GMT+3) on the 1st of July (for solar radiation calculations) which is the typical summer day analyzed by ECOTECT5.6 but using the average monthly meteorology of July which is the mid summer month instead for better representing all summer ranges of *T*a, *V* and *RH*, Tab.2. It is used here in this work to generate ambient meteorology for different urban planning scenario's comparisons. The main criteria assessed outdoors is the comfort level in terms of the modified PMV after [37] to be considered for transient conditions rather than the stationary PMV of Fanger [38]. The ambient conditions corresponding to specific outdoor PMV, PMVo, if closed to accepted levels for native people by adaptation, will in turn consume certain amount of energy to achieve indoor comfort, PMVi. This coupled comfort levels will affect producing certain amount of CO_2 emissions. Tab.2 illustrates meteorology, human outdoor biometeorology and model area resolution parameterization for urban simulations. PMVo, from a pedestrian comfort point of view can be recorded at height between 1.2-1.75m above ground level of which 1.60m a.g.l. has been selected to record PMVo at.

Table.2: Meteorology, Biometeorology and model resolution inputs used in simulations.

No.	Parameter	Value
1	*Ta*	301.95° K
2	*RH*	59%
3	*V*	3.5 m/s at 10m height
4	Ground temperature	301.65 ° K from 0-0.5m and 297.45° K from 0.5-2m
5	Ground humidity	BC & DS1; 20% from 0-0.5m and 30% from 0.5-2m DS2 & DS3; 70% from 0-0.5m and 80% from 0.5-2m
6	U value Walls	1.7
7	U value Roofs	2.2
8	Albedo Walls	0.25 for all except DS3; 0.15
9	Albedo Roofs	0.15 for all except DS3; 0.40
10	Albedo Pavement	0.40
11	Pavement Emissivity	0.90
12	Human walking speed	1.1 m/s
13	Pedestrian Clo.	0.50
14	BC resolution	5.70 × 4.56m
15	DS1 resolution	5.70 × 4.56m
16	DS2 resolution	6.50 × 5.80m
17	DS3 resolution	6.50 × 5.80m

2.3 Output extraction and slice criteria

ENVI-met allows meteorology outputs for each grid in the model area and in slices at different height within the model. It can produce any meteorological value for all grids of the model. The mean values of meteorological parameters at 1.6m from 06-18 LST have been averaged to be used as hourly inputs. Slices of extracted Numerical output allow selection of specific height to be used up to the model boundary. This is decided before running the model where one of two vertical grid systems can be chosen. But why these parameters were averaged at 1.6m a.g.l; it is the maximum value among 1.2-1.75m that can represent pedestrian comfort as well as a height within the canopy layer to be used as representation for whole site's hourly. The slice height that contains meteorology output after 1.6m is 2.5 which cannot represent comfort from pedestrian point of view.

2.4 Coupling outdoor-indoor meteorology

As ENVI-met doesn't have the capability to simulate indoor climate, DesignBuilder2.0.5 has been used for investigating the mean comfort level and CO2 production for the whole selected building. DesignBuilder2.0.5 is a 3-D comprehensive interface built over Energy Plus3.1, [39], dynamic model that can simulate indoor thermal interactions, calculate comfort levels and CO2 production [40]. The building is designed by the author as (G+2), fig.3, built in 2006 as small multi family housing contains almost 6 typical flats, 5 people/flat. Ground floor area is 300sqm where typical floors are 330sqm, it has window to wall ration of about 15% and it is oriented along the N-S axis. Despite the building is already existing in BC, it has been assumed that the same building will be constructed in all DS1-3 in order to fix differences in CO_2 production only to the built environment modifications not to the different housing typology. The mechanical cooling system is split with separate mechanical ventilation in a multi zones model for all zones except for bathrooms, kitchens, stair cases and the whole basement. Means of *air temperature, wet bulb temperature, relative humidity, global radiation, short-wave direct and diffuse radiations and wind speed* of all site outdoor grids were added in their time places in a comma separated file (CSV) file extension. This allow easily editing hourly meteorology in a typical meteorological year (TMY2) weather data format which can be used for Egypt, [41]. As DesignBuilder2.0.5 uses (EPW) weather files, EnergyPlus converter tool has been used for conversion after writing new hourly data in the (CSV) file. One can say; this doesn't represent a typical year, but actually DesignBuilder2.0.5 cannot upload the weather file to simulation core without using a statistical file that record the slight modification made to the typical year by means of the new hourly data generated by ENVI-met. In another word, the TMY2 has been also statistically modified to represent the urban form adaptation from design suggestions of the neighborhood. Wet bulb temperature needed to complete the new hourly weather data (12h) is calculated from *Ta*, *RH* and air pressure at the elevation of the site (100439 Pascal at 74 above sea level). After all, building design temperature is 23°C whereas ambient air temperature calculated statistically by EnergyPlus and used in DesignBuilder is maxima of 44°C and 43°C for BC and DS1-3 respectively and minima of 24°C for all of them. In Fahmy et al., [27], snapshot receptors were used to record the near walls meteorology for a limited microclimate area in the fifth community. In this paper, urban site has been simulated in a local scale. Therefore, mean meteorology for the whole site can be representing ambient conditions for all site's buildings, which is better than using a WMO weather station measurements of single point to represent climate condition of a city (WMO no. 623660 at Cairo international airport weather station). Moreover, this is better than having receptors surrounding each building which means more than the receptors' no. allowed in ENVI-met (99) whilst having large number of simulations for each building which is very time consuming. Simulations of each case in this work took about 7-10 days to build the model, about 7 days to simulate it and about 5 days to extract numerical data, indoor simulations and plot the outputs. Eventually, local scale meteorology means have been used to compile the (EPW) file for usage by DesignBuilder.

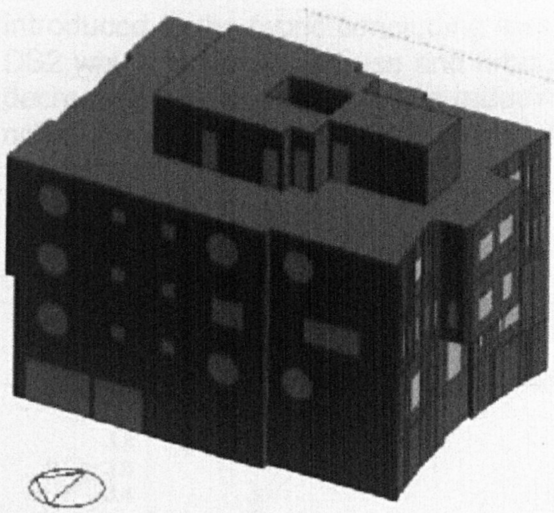

Fig.3: The building model built in DesignBuilder2.0.5 including its basement which is not included in CO2 production calculations (Doesn't have HVAC system).

3. RESULTS

3.1 Urban form and comfort levels

Fig.5, illustrates the values of PMVo. Basically, by increasing *Dc*, PMVo showed reductions of the whole suggestions curves' trends if compared with BC. By solar altitude increases, street canyons within each case urban pattern is heated reaching the maximum PMVo at 13.00 for BC and DS1 which are the same zoning. By closing to sunset, and due to the availability of sensible heat release at early evening, the comfort levels decreases tremendously from 4.9 at 13.00LST to only 2.0 at 18.00LST by applying DS1. PMVo has recorded reductions from BC to DS1 of about 0.1-0.7 due to the clustered form which is the only difference from BC in addition to the increased compactness.

As DS2 and DS3 are same zoning (master planning), their PMVo curves shed the same trend of urban patterns and street canyon thermal behavior but with remarkable difference from BC and DS1. Their comfort peak was at 15.00 instead of 13.00 which are explained by the increased *Dc* that offered more direct shelter, refer to Table.1. The evening behavior is also different which can not be owed to *Dc* as the neighborhood quarters' public green areas offers nocturnal cooling nodes. It can be owed to the increased no of dense trees used (LAI of 3) that have been used to provide more shelter, but same time it have increased the long-wave radiation from ground and near walls trapped by the trees' canopies itself which is in good agreement with results of Fahmy et al., [32]. The different zoning, *Dc*, number of trees and clusters aspect ratios with orientation moved the whole comfort trend as if the urban form acted as a mass wall. In comparison with BC, DS2 recorded PMVo differences of about 1.7 at 6.00LST crossing the BC curve at almost 14.20LST and recorded increased difference from BC of about 0.6-1.4 early evening until sunset. Frankly, the local scale clustered form with dense trees' arrangements delayed heating by day and cooling by night. It can be said that the whole urban passive cooling system configured turned the neighborhood form into *urban thermal mass* that shifted PMVo curves from BC as shown in fig.4. The usage of high roof Albedo values in DS3 concluded less diffused short-wave radiation introduced to the fabric concluding less comfort levels by day in comparison to DS2 which is same land use and urban planning parameters. By solar altitude decreases the Albedo effect on reducing heat gain is minimized which can be noticed from the matching comfort levels of DS2 and DS3 from 15.00LSt until sunset.

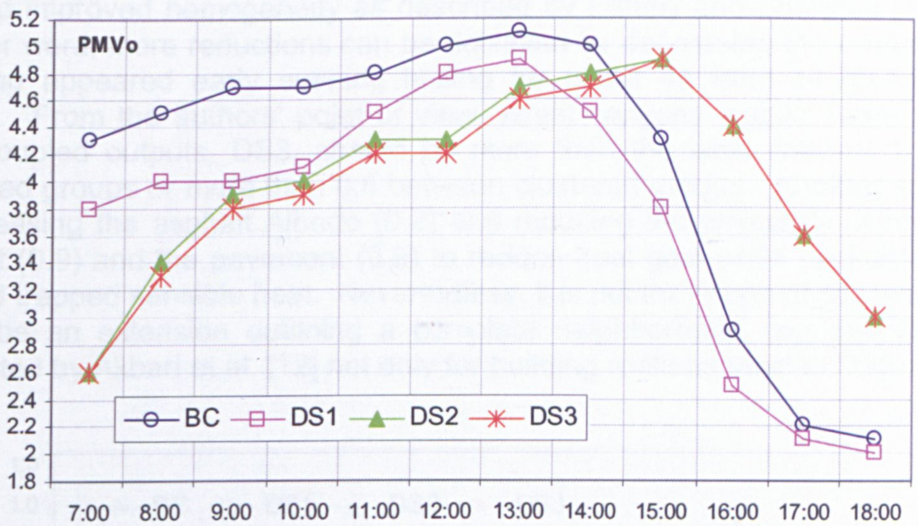

Fig.4: Mean outdoor comfort levels for all neighborhood urban spaces.

3.2 Building CO_2 production

Fig, 5 and 6 show mean building PMVi levels and CO_2 production per Kwh corresponding to mean ambient conditions at 1.6 a.g.l which in turn corresponding to mean PMVo of all urban spaces of the neighborhood at same height. The same trend of PMVo can be noticed in PMVi regardless its close records for all cases which are owed to the mechanical cooling that kept comfort levels close to each other and close to comfort standards of ISO7730. Surprisingly, CO_2 produced from DS1 has exceeded that of BC starting from 12.00LST and towards sunset reaching 1.5Kg at 18.00LST. The success that the clustered form of DS1 has achieved in comparison to BC appeared in PMVo hasn't been achieved in terms of CO_2 emissions. It used only clustered form without structuring the green coverage or intensively using urban trees and didn't help much modification of ambient climate conditions in terms of PMVo which recorded only 4.9 for DS1 in comparison to 5.1 for BC. The application of the passive thermal comfort system used by Fahmy and Sharples [14], on a neighborhood scale with enhanced clustered form oriented 15° from E-W axe as an optimization for mid-latitude location, performed generally better regardless the urban mass effect discussed in 3.1. The compiled ambient conditions of DS2 reduced CO_2 production by 1.7% of about 0.6Kg from BC at 13.00LST and start to exceed BC at 14.00LST at which the urban mass effect starts to take place. DS2 had maximum day time CO_2 reductions of 1.7Kg at 10.00LST. The only difference of DS3 from DS2 is the roof surfaces' Albedo as shown in Table.2. In this suggested master plan, CO_2 reductions at peak time reached 2.8% of about 1.0Kg from BC. In fact, the sum of the 12h CO_2 production for all BC and DS1-3 revealed that only DS3 succeeded in coupling between reduced outdoor-indoor comforts levels and reduced CO_2 production. Despite DS3 CO_2 sum of the 12h equaled 404k.g compared with 404.3Kg for BC, the small daily sum difference gives an idea about the homogeneity of DS3 urban form. Its compactness could have allowed more nocturnal cooling for each clusters' group within each quarter if the local urban radiant heat island, LUHI, showed improved homogeneity as described by Fahmy and Sharples [14]. In another word, more reductions can be achieved by decreasing *the urban mass time lag* appeared early evening lasting for about 4h from 14.20LST until sunset. From the authors' point of view, street canyons' aspect ratios of the best coupled outputs, DS3, should be more than the used ratio of 1 within clustered groups or more than 0.6 between clustered groups. Another solution is increasing the asphalt Albedo (0.2) and reducing the emissivity of both the asphalt (0.9) and the pavement (0.9) to reduce heat gain while minimizing the emitted trapped sensible heat. Nevertheless, it is not the scope of this work and could be an extension outlining a complete neighborhood cool surfaces as presented by Akbari et al. [12] not only for building roofs as used in DS3.

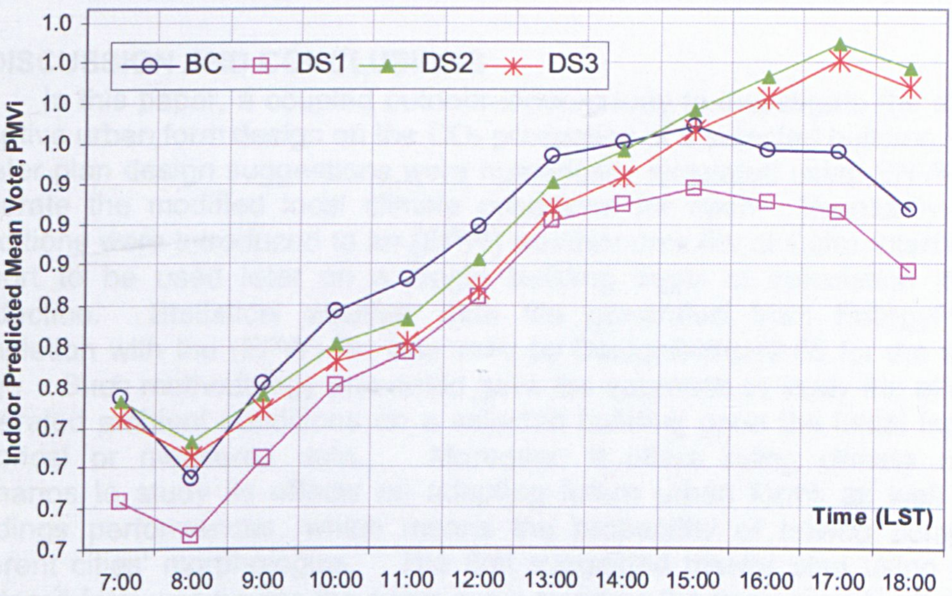

Fig.5: Mean indoor comfort levels of the selected building.

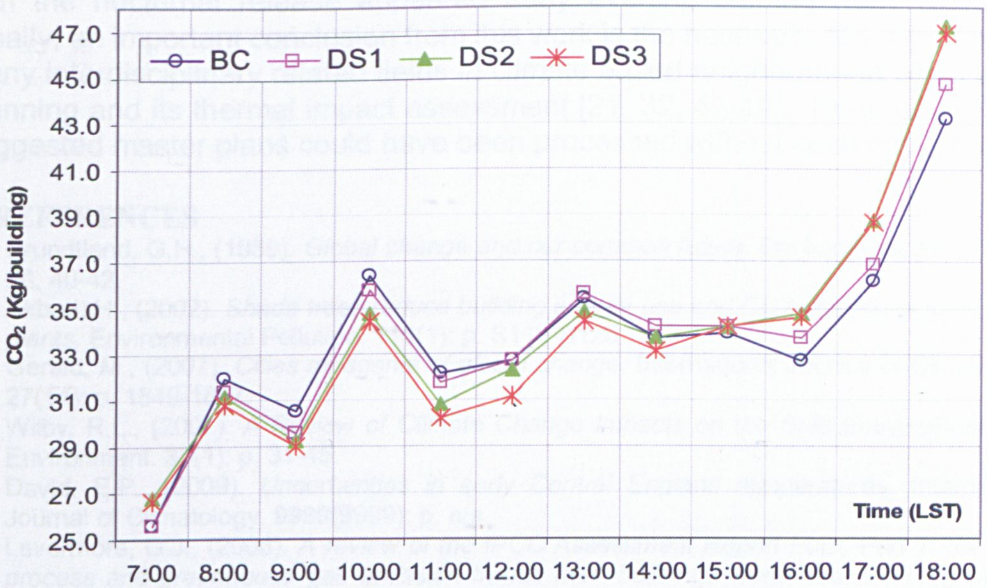

Fig.6: CO_2 production of the selected building.

4. DISCUSSION AND CONCLUSIONS

In this paper, a coupled outdoor-indoor study to investigate the effect of adaptive urban form design on the CO_2 production of a selected building. Three master plan design suggestions were numerically simulated using ENVI-met to generate the modified local climate conditions for each. Eventually, these conditions were introduced to an (EPW) weather data file of Cairo International Airport to be used later on a single building scale to calculation its CO_2 production. Statistical weather data file generated from EnergyPlus in completion with the (EPW) file was used by DesignBuilder2.05 for the second stage. Such methodology presented gave the approach to study the effects of generated ambient conditions on a selected building upon the initial inputs of historical or measured data. Moreover, it offers using climate change scenarios to study its effects on adapting future urban forms as well as on buildings performances, which means the probability of having completely different cities' morphologies. The first suggested master plan using only a clustered form was having the same curve trend as the base case in all studied parameters, outdoor and indoor comfort as well as the CO_2 production but down shifted all the time. Both of the second and third suggested master plans made a delay in total urban heat gain in addition to delay in evening heat release due to the increased compactness within cluster groups as well as the increased number of dense trees. Such differences moved all parameters to the right of the plot area from base case curves which are defined as the urban thermal mass effect. CO_2 was reduced by about 1.7 and 2.8% for the second and third suggestions whilst the first increased it by 0.6%. Moreover, as the third master plan succeeded at day time in coupling reductions for outdoor-indoor comfort levels as well in CO_2 production, an intensive application of the fabric cool surfaces could have extended this success, but caution for urban spaces' design habitats and usages at night time has to be considered in order to cope with the nocturnal release appeared early evening starting from 15.00LST. Finally, an important conclusion from this work is the necessity of integrating the many interdisciplinary related fields in climate based neighborhood scale urban planning and its thermal impact assessment [21, 32, 42-44]. None of the three suggested master plans could have been processed without such integration.

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